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Advanced Space System Analysis Software — Technical, User, and Programmer Guide

Final Report

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16 Abstract

The LASS computer program provides a tool for interactive preliminary and conceptual design of LSS. This document describes the capabilities added to the LASS program as a result of completion of contract NAS1-16447. Eight new program modules were developed, including four automated model geometry generators, an associated mass properties module, an appendage synthesizer module, an rf analysis module, and an orbital transfer analysis module. The existing rigid body controls analysis module was modified to permit analysis of effects of solar pressure on orbital performance. A description of each module, user instructions, and programmer information are included in the report.

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TABLE OF CONTENTS

SUMMARY 1

1.0 SCOPE OF TASK III - COMPUTER-AIDED DESIGN AND ANALYSIS 2

2.0 COMPUTER PROGRAM DOCUMENTATION 2

2.1 Box Ring 4

2.2 Contiguous Box Truss Module 15

2.3 Radial Rib Module 25

2.4 Hoop and Column Module 34

2.5 Mass Properties Module 40

2.6 Orbital Transfer Module 48

2.7 Rf Analysis Module 52

2.8 RCD Module 55

2.9 Appendage Synthesizer Module 101

2.10 Control Bandwidth Estimation 114

3.0 DATA FILE DESCRIPTION 122

4.0 REFERENCES 165

ADVANCED SPACE SYSTEMS ANALYSIS SOFTWARE- TECHNICAL, USER AND PROGRAMMER GUIDE

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SUMMARY

LSS preliminary and conceptual design requires extensive iteration because of the significance of structural, thermal, and control intercoupling. The objective of Task III is to expand the capabilities of the existing NASA-Langley LASS program (ref. 1). LASS is an interactive LSS analysis and design computer program that provides rapid geometric modeling capability, performs preliminary structural, thermal, and controls analyses, and provides an interfacing mechanism for execution of detailed interdisciplinary analyses. Completion of this task has resulted in automated modeling capability for box truss ring, contiguous box truss, radial rib, and hoop/column structures and associated appendages. An interactive module permits modification and evaluation of mass properties for all structure types. Modules have been developed to permit analysis of orbital transfer propulsion requirements and rf gain loss due to reflector surface distortion. The rigid body controls analysis module has been modified to permit analysis of the control requirements imposed by solar pressure, aerodynamic drag, and gravity gradient. This report contains a description of each added or modified module including user instructions and programmer information.

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1.0 SCOPE OF TASK III - COMPUTER-AIDED DESIGN AND ANALYSIS

The objective of Task III is to provide support in the development of an interactive analysis and design computer capability to be used to perform preliminary and conceptual design of LSS. There are two levels of analysis techniques that must be addressed. The first level involves an overview of the salient features of various conceptual designs. The second is a more detailed approach that involves in-depth structural design and analysis. The former technique can be performed through use of first order system approximations that lend themselves to interactive analysis. The latter makes use of larger, longer-running computer programs that are implemented by interfacing with the interactive mode programs. To provide and expand each of these capabilities at NASA-Langley the following subtasks were performed in Task III.

(1) Develop an understanding of the LASS program capabilities existing at the start of the program.

(2) Prepare and present for LARC approval a development plan identifying the upgraded LASS capability.

(3) Implement the approved plan.

(4) Prepare and deliver Task III-related documentation. Also, a computer program would be developed relating to work performed in Task II, LSS Control/Structure Interaction.

2.0 COMPUTER PROGRAM DOCUMENTATION

Completion of subtasks 1 and 2 of the Task III effort resulted in definition of a development plan that would expand the LASS program by adding and modifying modules as indicated in Figure 2.1.

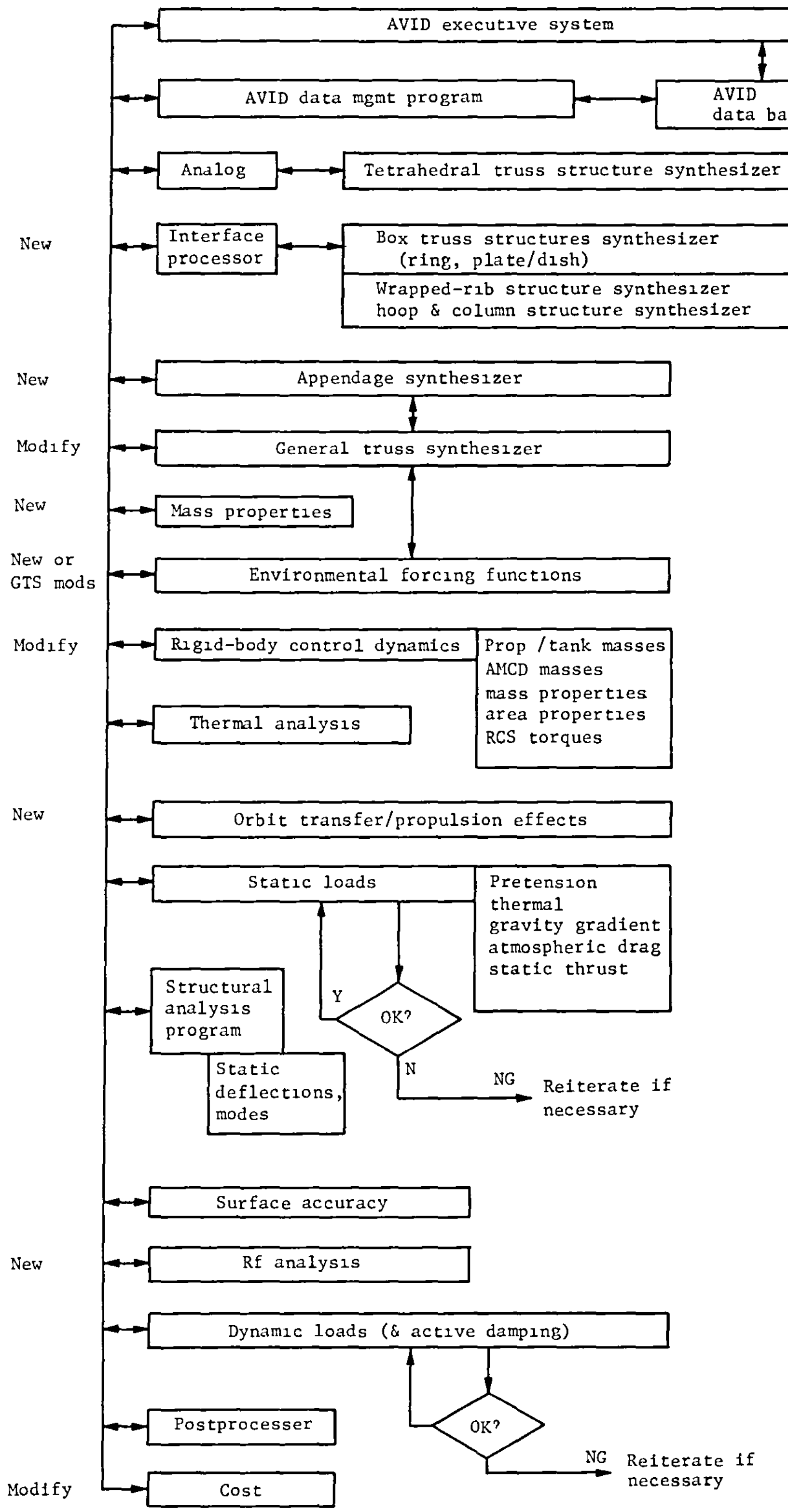


Figure 2.1. - Flow diagram of LASS with expanded capability.

As development and modification of modules were performed, it was mutually decided to revise the plan to facilitate new module implementation. Specifically, modifications to the GTS module would require significant effort because it was tied so closely to the TTSS model. Also, it was more efficient to incorporate the environmental forcing functions module as a subsection of the RCD module. The resulting expanded LASS capability provided by completion of Task III involved eight new modules:

(1) Box truss ring model generator;

(2) Contiguous box truss model generator;

(3) Radial rib model generator;

(4) Hoop and column model generator;

(5) Mass properties;

(6) Orbital transfer;

(7) Rf analysis;

(8) Appendage synthesizer.

In addition, the RCD module was modified to add the effects of solar pressure and to permit execution without requiring prior execution of the TISS and GTS modules. User and program documentation pertaining to each new or modified module follows.

2.1 BOX RING MODULE

The box ring model generator provides a user with the capability of interactively specifying the input parameters to create NASTRAN format (MSC version) bulk data input and to determine structural model mass properties.

2.1.1 Box Ring Module Technical Description

The Box Ring structure is described graphically in Figure 2.1.1. The model coordinate system origin is located at the center of the regular polygon formed by the box inner or outer surface tubes, with Z = 0 at the bottom surface plane. Using this model origin, the model generator calculates the outputs shown in Figure 2.1.2 for the defined inputs. The required tube data include cross-sectional area and tube material density.

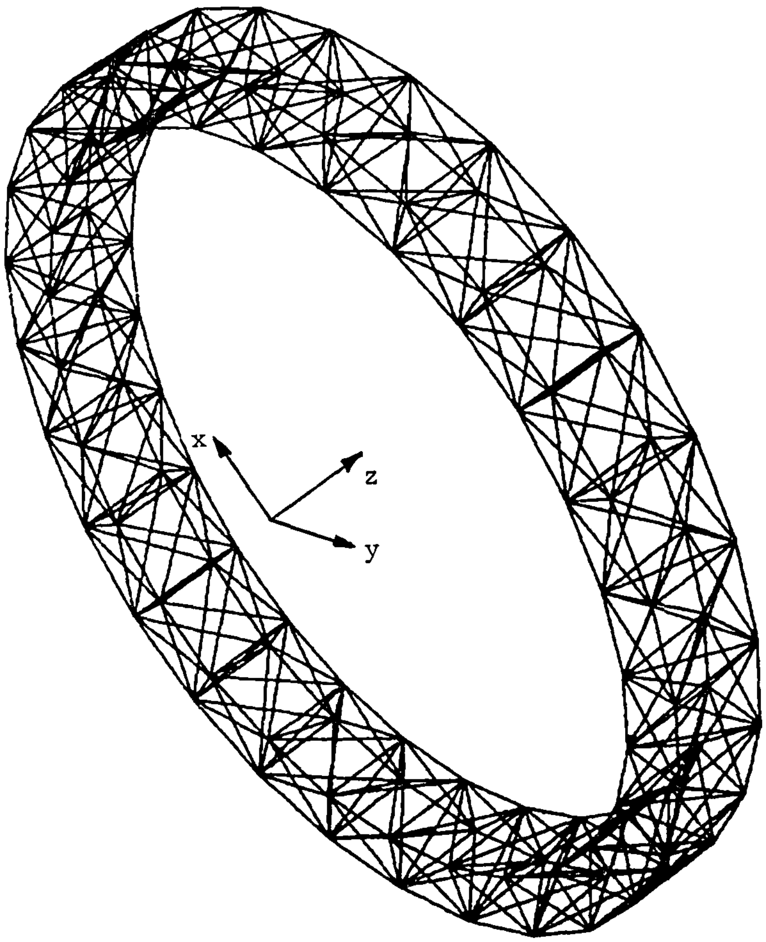


Figure 2.1.1. - Box ring structure.

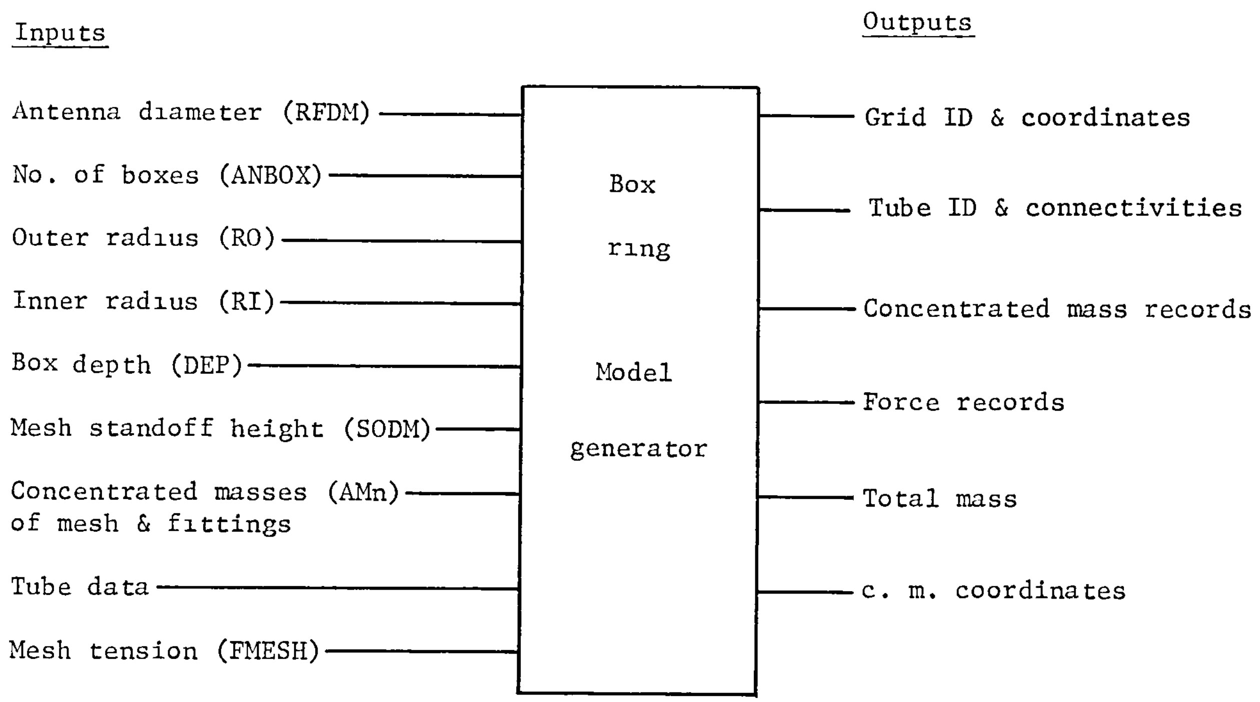


Figure 2.1.2. - Box ring module input/output.

The box tubes are grouped into five categories as shown in Figure 2.1.3. All tubes are modeled as rod elements. Node and element numbers are shown for a sample box truss.

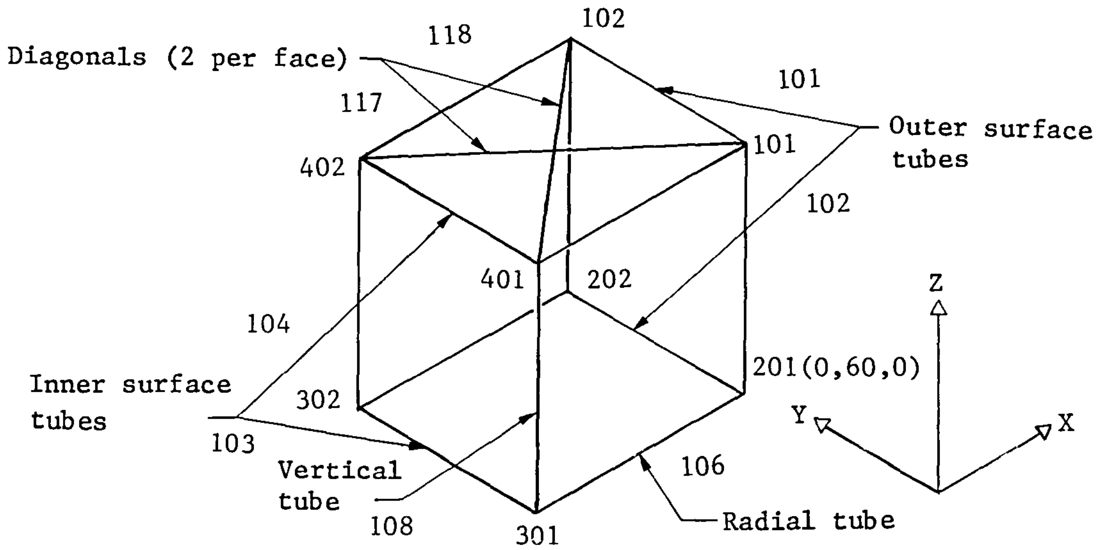


Figure 2.1.3. - Box ring tube identification.

As the grid coordinates are determined, they are stored in a local array (GRIDD) for subsequent use in determining structural element lengths and locations. As each grid is defined its record is written to local file TAPF2.

When all grids are defined, the program starts definition of structural elements. The appropriate parameters for NASTRAN ROD records are written to TAPF2. As each ROD record is generated its connectivity information and tube type is stored in local array IELM for subsequent length and plotting definition. After completing ROD records the CONM2 records are defined, written to TAPE2, and stored in GRIDD (1,5).

The final section of the model generator routine creates the External Force records at grids. These forces are induced in the structure due to mesh or membrane tensioning. The user may select a configuration with or without

standoffs. Figure 2.1.4 shows the force resolution at the inner and outer nodes for both cases. The tension force (F_T) at each connection point is given by:

$$F_T = 2\ F_m\ R_I \sin\left(\frac{\pi}{NBOX}\right) \quad (1)$$

Where: F_m = mesh tension (N)

R_I = inner radius of structure (m)

NBOX = number of boxes in ring

For a model with standoffs the forces on the nodes are found from:

$$F_1 = F_T \sin\left(\alpha_1\right) + F_2 \sin\left(\alpha_2\right)$$

$$F_2 = F_T \cos\left(\alpha_1\right)/\cos\left(\alpha_2\right)$$

$$\alpha_1 = \tan^{-1}\left[\left(\frac{depth}{2} + \ell\right)\right] /R_1$$

$$\alpha_2 = \tan^{-1}\left(\frac{\ell}{R_o - R_I}\right) \quad (2)$$

Where: R_o = outer box ring radius

ℓ = standoff height

depth = box truss depth

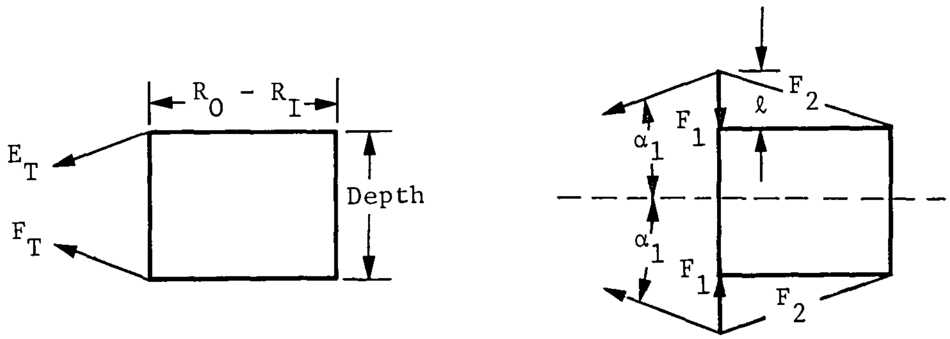


Figure 2.1.4. - Mesh tension force resolution at nodes.

On completion of module execution, the data generated are stored in a dynamic model file, data base file, and mass properties matrices file for subsequent mass properties analysis or structural analysis.

2.1.2 Box Ring Module User Instructions

On entering the box ring model generator module the user is asked to input the name of an input data base file by the prompt:

```
ENTER DATA BASE FILE NAME FOR INPUT
   0-DEFAULT FILE NAME(LASSDB)
  PFN-USER DEFINED FILE NAME,

? GR28BOX
```

The next prompt requests selection of Box Ring sizing mode, either manual or automatic by:

```
SPECIFY SETUP MODE
                  1 - AUTOMATIC
                  2 - USER SELECTED
? 2
```

(At present, the automatic sizing is not implemented.)

The parameters required for model geometry definition are next input or modified as shown in the following. Tests are performed to ensure that valid values are specified for number of bays and radius. If not the user is prompted to supply data as required.

```
 INPUT DESIRED VALUES FOR RFDM,FOVERD,ANBOX,ANBAYS,RO,RI,DEP,FMESH,NFDS
1
+           BOX RING ASSA TEST CASE


 BOX RING MODEL GENERATOR INPUT ITEMS

      103 00         1  RFDM    -RADIO FREQUENCY DIAMETER (METERS)
      2 0000         2  SHAPE   -SHAPE FLAG  1=PARABOLA, 2=SPHERE, 3=FLAT
      2 0000         3  FOVERD  -FOCAL LENGTH TO RF DIAMETER RATIO
      28 000         4  NBAYS   -NUMBER OF BAYS IN REAL DISH STRUCTURE
      28 000         5  ANBAYS  -ANALYSIS NUMBER OF BAYS
    0                6  SODM    -MESH STAND-OFF DISTANCE (METERS)
      1 0000         7  MOUNTF  -DISH MOUNTING FLAG  0=APEX, 1=EDGE, 3=FREE
    0                8  NMODE   -NUMBER OF MODE SHAPES (0=NO SAP MODELS)
    0                9  XANACM  -X COORDINATE FOR ANGULAR ACCELERATION (METERS
    0               10  YANACM  -Y COORDINATE FOR ANGULAR ACCELERATION (METERS)
    0               11  ZANACM  -Z COORDINATE FOR ANGULAR ACCELERATION (METERS)
    0               12  TUBTYP  -STRUT TYPE  0=L/R, 1=EULER, 2=ISOG, 3=TRUSS
      60 000        13  RO      -OUTER BOX RING RADIUS (METERS)
      51 500        14  RI      -INNER BOX RING RADIUS (METERS)
      14 000        15  DEP     -BOX TRUSS DEPTH (METERS)
      45 410        16  FMESH   -MEMBRANE AXIAL FORCE FACTOR
      4 0000        17  NFDS    -NUMBER OF FEED SUPPORT BEAMS
       90800        18  AM1     -CONCENTRATED MASS AT OUTER TOP GRID(KG)
       90800        19  AM2     -CONCENTRATED MASS AT OUTER BOTTOM GRID(KG)
      15 450        20  AM3     -CONCENTRATED MASS AT INNER BOTTOM GRID(KG)
      15 450        21  AM4     -CONCENTRATED MASS AT INNER TOP GRID(KG)
    0               22  AMHING  -MIDLINK HINGE MASS(KG)
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD,
       2 TO ENTER A NEW TITLE,
    OR 9 TO RETURN TO THE EXEC
? 0
```

The user is presented with the following in order to specify element properties, repeated for each of the five tube types. If zero area or density is specified the user is reprompted to supply valid values.

```
            BOX RING ASSA TEST CASE


 OUTER TUBE PROPERTIES

    1 46000E-04      1   AREA     -CROSS SECTIONAL AREA (SQ M )
    3 77000E-07      2   J        -TORSIONAL CONSTANT (M**4)
    0                3   C        -TORSIONAL STRESS COEFFICIENT
    0                4   RNSM     -NON STRUCTURAL MASS PER UNIT LENGTH
    1 38000E+11      5   E        -YOUNG'S MODULUS(NT/SQ M )
    2 06000E+10      6   G        -SHEAR MODULUS(NT/SQ M )
    0                7   NU       -POISSON'S RATIO
     1939 3          8   RHO      -MASS DENSITY(KG/CU M )
    0                9   TEC      -THERMAL EXPANSION COEFFICIENT
    0               10   TREF     -THERMAL EXPANSION REFERENCE TEMP
    0               11   GE       -STRUCTURAL DAMPING COEFFICIENT
    0               12   ST       -TENSION STRESS LIMIT (NT/SQ M )
    0               13   SC       -COMPRESSION STRESS LIMIT(NT/SQ M )
    0               14   SS       -SHEAR STRESS LIMIT(NT/SQ.M )
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD,
       2 TO ENTER A NEW TITLE,
    OR 9 TO RETURN TO THE EXEC
? 0

            BOX RING ASSA TEST CASE


 INNER TUBE PROPERTIES

    1 28000E-04      1   AREA     -CROSS SECTIONAL AREA (SQ M )
    2 52000E-07      2   J        -TORSIONAL CONSTANT (M**4)
    0                3   C        -TORSIONAL STRESS COEFFICIENT
    0                4   RNSM     -NON STRUCTURAL MASS PER UNIT LENGTH
    1 38000E+11      5   E        -YOUNG'S MODULUS(NT/SQ M )
    2 06000E+10      6   G        -SHEAR MODULUS(NT/SQ M )
    0                7   NU       -POISSON'S RATIO
     1939 3          8   RHO      -MASS DENSITY(KG/CU.M.)
    0                9   TEC      -THERMAL EXPANSION COEFFICIENT
    0               10   TREF     -THERMAL EXPANSION REFERENCE TEMP
    0               11   GE       -STRUCTURAL DAMPING COEFFICIENT
    0               12   ST       -TENSION STRESS LIMIT (NT/SQ M )
    0               13   SC       -COMPRESSION STRESS LIMIT(NT/SQ M )
    0               14   SS       -SHEAR STRESS LIMIT(NT/SQ M )
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD,
       2 TO ENTER A NEW TITLE,
    OR 9 TO RETURN TO THE EXEC
? 0
```

```
|
|          BOX RING ASSA TEST CASE

 RADIAL TUBE PROPERTIES

    1 09000E-04      1   AREA    -CROSS SECTIONAL AREA (SQ M )
    1 59000E-07      2   J       -TORSIONAL CONSTANT (M**4)
    0                3   C       -TORSIONAL STRESS COEFFICIENT
    0                4   RNSM    -NON STRUCTURAL MASS PER UNIT LENGTH
    1 38000E+11      5   E       -YOUNG'S MODULUS(NT/SQ M )
    2 06000E+10      6   G       -SHEAR MODULUS(NT/SQ M )
    0                7   NU      -POISSON'S RATIO
     1939 3          8   RHO     -MASS DENSITY(KG/CU M )
    0                9   TEC     -THERMAL EXPANSION COEFFICIENT
    0               10   TREF    -THERMAL EXPANSION REFERENCE TEMP
    0               11   GE       STRUCTURAL DAMPING COEFFICIENT
    0               12   ST      -TENSION STRESS LIMIT (NT/SQ M )
    0               13   SC       COMPRESSION STRESS LIMIT(NT/SQ M )
    0               14   SS      -SHEAR STRESS LIMIT(NT/SQ M )
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD,
       2 TO ENTER A NEW TITLE,
    OR 9 TO RETURN TO THE EXEC
? 0


|
|          BOX RING ASSA TEST CASE

 VERTICAL TUBE PROPERTIES

    2 51000E-04      1   AREA    -CROSS SECTIONAL AREA (SQ M )
    2 99000E-07      2   J       -TORSIONAL CONSTANT (M**4)
    0                3   C       -TORSIONAL STRESS COEFFICIENT
    0                4   RNSM    -NON STRUCTURAL MASS PER UNIT LENGTH
    1 38000E+11      5   E       -YOUNG'S MODULUS(NT/SQ M )
    2 06000E+10      6   G       -SHEAR MODULUS(NT/SQ M )
    0                7   NU      -POISSON'S RATIO
     1939 3          8   RHO     -MASS DENSITY(KG/CU M )
    0                9   TEC     -THERMAL EXPANSION COEFFICIENT
    0               10   TREF    -THERMAL EXPANSION REFERENCE TEMP
    0               11   GE      -STRUCTURAL DAMPING COEFFICIENT
    0               12   ST      -TENSION STRESS LIMIT (NT/SQ M )
    0               13   SC       COMPRESSION STRESS LIMTT(NT/SQ M )
    0               14   SS      -SHEAR STRESS LIMIT(NT/SQ M )
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD,
       2 TO ENTER A NEW TITLE,
    OR 9 TO RETURN TO THE EXEC
? 0
```

```
DIAGONAL TAPE PROPERTIES

   2 33000E-05      1  AREA   -CROSS SECTIONAL AREA (SQ M )
   0                2  J      -TORSIONAL CONSTANT (M**4)
   0                3  C      -TORSIONAL STRESS COEFFICIENT
   0                4  RNSM   -NON STRUCTURAL MASS PER UNIT LENGTH
   1 38000E+11      5  E      -YOUNG'S MODULUS(NT/SQ M )
   2 06000E+10      6  G      -SHEAR MODULUS(NT/SQ M )
   0                7  NU     -POISSON'S RATIO
    1939 3          8  RHO    -MASS DENSITY(KG/CU M )
   0                9  TEC    -THERMAL EXPANSION COEFFICIENT
   0               10  TREF   -THERMAL EXPANSION REFERENCE TEMP
   0               11  GE     -STRUCTURAL DAMPING COEFFICIENT
   0               12  ST     -TENSION STRESS LIMIT (NT/SQ M )
   0               13  SC     -COMPRESSION STRESS LIMIT(NT/SQ M )
   0               14  SS     -SHEAR STRESS LIMIT(NT/SQ M )
ENTER 0 IF INPUT IS OK
```

Once all tube properties have been satisfactorily specified, the program generates the information necessary to represent a Box Ring Model.

The last inputs requested of the user are the data file name in which input items are to be stored,

```
ENTER NAME DATA BASE FILE IS TO BE REPLACED AS
  0 - DEFAULT FILE NAME(LASSDB),
 PFN - PERMANENT FILE NAME

? DB28BOX
```

the name of the file to which the model data (presently in NASTRAN format) is to be written,

```
ENTER NAME DYML FILE IS TO BE REPLACED AS
   0 - DEFAULT FILE (DYML)
 PFN - PERM  FILE NAME

? DY28OR
```

and the name of the file to which the mass properties matrices will be written.

```
INPUT NAME OF MASS PROPERTIES MATRICES FILE
? MASS80K
```

At this point program execution terminates.

2.1.3 Box Ring Module Programmer Information

The program is overlayed with three primary overlays; BRING (1,0) BRING (2,0), and BRING (3,0). The functions of each are as follows:

(1) Overlay BRING (1,0)

This overlay provides for initialization and user input of required data. The first called subroutine, INIT, sets up I/O parameters based on the user terminal type. Subroutine INTBR initializes Box Ring input parameters.

Subroutine BRINPT provides for user selection of the input Data Base file name. If such a file does not exist the user is told so and the required inputs are listed out. A call to SETUP will eventually permit automatic as well as manual definition of Box Ring input parameters; presently, it is not functional.

Library routine RDDTBS retrieves data from the user specified data file.
Subroutine PRNTIN controls display of user information.
Subroutine CHNGIN permits interactive input/modification of data.

(2) Overlay BRING (2,0)

This Overlay performs the model geometry definition function, generating GRID card images, CROD card images, CONM2 card images, and

FORCE1 card images for NASTRAN bulk data input deck formation. These records are written to local file TAPE2 for subsequent storage in a permanent DYML type file. The grid numbers are in the ranges shown below.

Outer top grids	100-199
Outer bottom grids	200-299
Inner bottom grids	300-399
Inner top grids	400-499

Subroutines SETNOD and SETELM write grid and element data to arrays IELM and GRIDD to permit rapid access to coordinate, mass, and connectivity information when calculating member lengths and mass properties. These arrays may also be used to set up plot files for model plots. NEL and NG are the number of elements and number of grids contained in the model and are determined through the calls to SETNOD and SETELM.

(3) Overlay BRING (3,0)

On completion of calculations the output data base file name is defined and written and the model data are written to the DYML file. The mass properties matrices file is created from local file TAPE8. This file contains arrays GRIDD, IELM, and TUBP, plus variables NEL and NG. These data are used on subsequent execution of the Mass Properties Module. This module should be executed immediately after the execution of the model generator module to permit calculation of and output of pertinent mass properties data.

2.2 CONTIGUOUS BOX TRUSS MODULE

The Contiguous Box Truss model generator module creates a NASTRAN structural model input file. It can create models having up to 1250 elements or 300 nodes. The model is assumed to be symmetrical in 4 quadrants. An example of a Contiguous Box Truss appears in Figure 2.2.1.

2.2.1 Contiguous Box Truss Module Technical Description

This module will automatically generate a contiguous truss structural model comprised of box trusses. Each box has the structural elements shown in Figure 2.2.1. The horizontal surface elements are modeled as cylindrical tubes with their cross sectional area calculated from the wall thickness and outer diameter or $A = \pi td$. The vertical tubes have cross sections as shown in Figure 2.2.2.

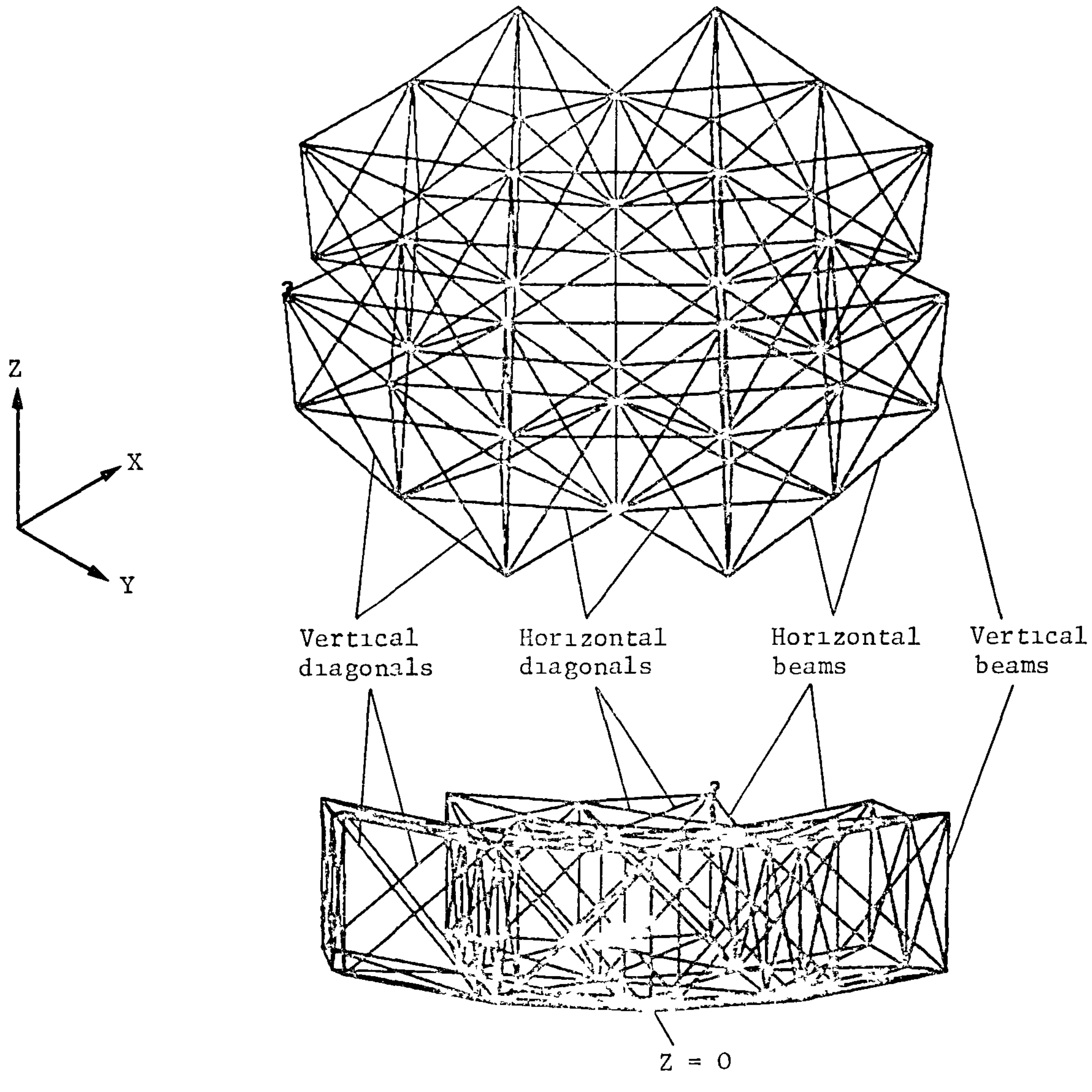


Figure 2.2.1. - Contiguous box truss structural model.

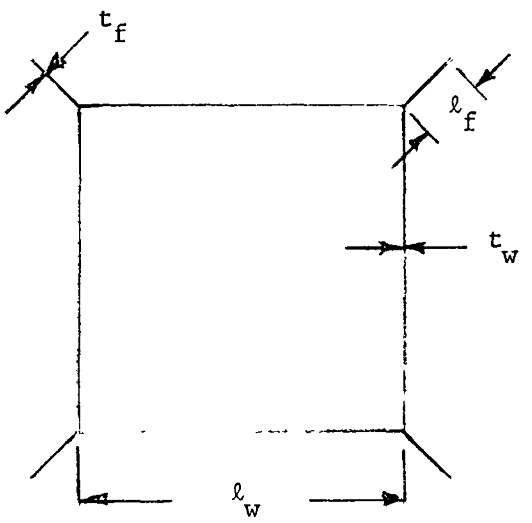


Figure 2.2.2. - Vertical finned tube cross section.

Vertical tube area is calculated as a function of the wall length (ℓ_w), wall thickness (t_w), fin length (ℓ_f), and fin thickness (t_f). Included in the program is the capability of defining different structural element cross-sectional areas as a function of their distance from the geometric model center. This capability was originally included to perform dynamic analyses of the coupling effects due to location of an orbital transfer propulsion engine at the model center. It was assumed that the structural elements would require decreasing load carrying capability as the distance from the engine increased radially. The zones are specified as some multiple of box length (L) as shown in Figure 2.2.3 where there are two property zones represented. In this example all elements, part of which lie in the region within 0.5L of the center, will have one set of physical properties and the remaining elements will have different physical properties. The program automatically determines which elements fall within the zones. A separate number of zones may be specified for each of the three types of elements modeled. These types are the cylindrical horizontal (surface) tubes, the finned vertical tubes, and the flat diagonal tapes.

The physical and material properties of the model elements are specified before execution. The material properties specified include F, G, η, and ρ, (Young's modulus, shear modulus, Poisson's ratio, density). These are used in definition of the dynamic model input file and for creation of a mass properties matrices file, both of which are later used for execution of the Mass Properties Module. In the current version, the contiguous truss module can accommodate models of up to 1250 elements or 300 nodes. This is sufficient to prepare contiguous truss structures of up to 42 bays. If more bays should be required the dimensions of the mass properties matrices (GPIDD, IFLM, TUBP) would need to be increased.

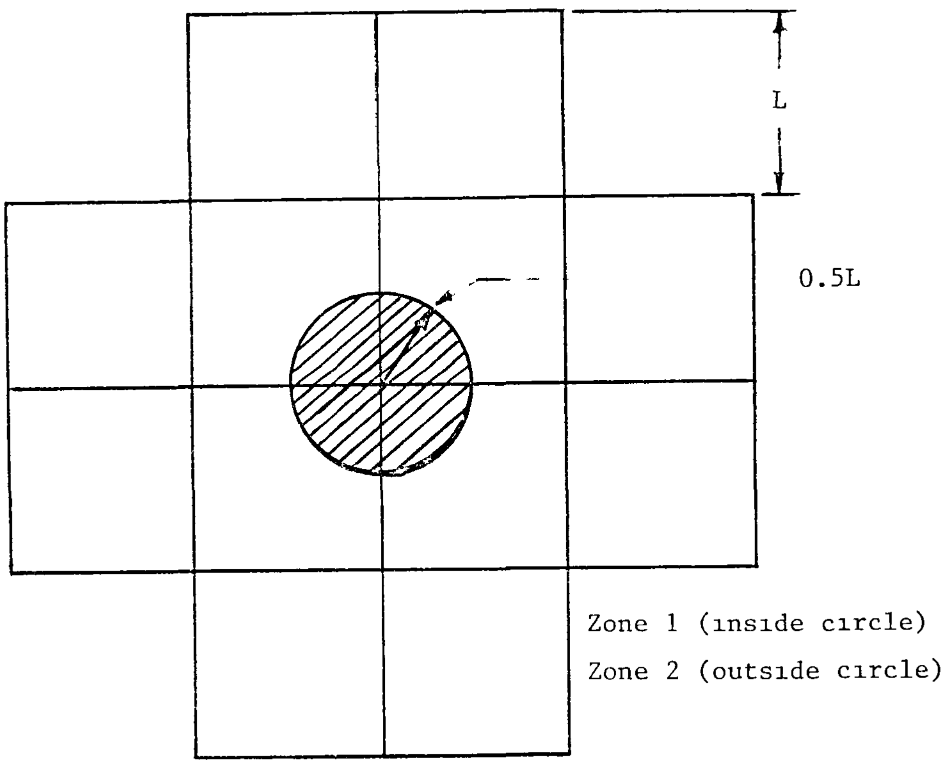


Figure 2.2.3. - Example of property zone definition.

Each bay consists of the structural members discussed previously plus end fittings, midlink hinges for folding members, and the diagonal tape attachment fittings. The masses of the endfittings (AMNODE) are represented as concentrated masses at grid points whose coordinates are at the endfittings. The origin (0,0,0) is at the top center of the model (top is the surface normally away from Earth) with the x-axis being tangent to the orbital path, z-axis vertical to Earth, and the y-axis orthogonal to x and z. Midlink hinge mass (AMHING) is used only for mass and inertia calculations because hinge points are not identified as GRID records in the dynamic model. The diagonal tape fittings mass is distributed through the tape itself.

The reflector surface subsystem mass is distributed over the surface nodes. This mass includes all component masses that are part of the reflector surface, its ties, drop cords, etc. These individual components are not presently isolated for purposes of mass properties analysis.

The outputs created from module execution are written to two files; one the dynamic model and the other the mass properties matrices file. A third output is the LASS data base file, which contains the required module input items. This file may be unchanged during execution if the structural model is not modified during the input phase. The user instruction section that shows a complete module user session follows.

2.2.2 Contiguous Box Truss Module User Instructions

On entering this module the user is prompted to enter the desired input data base file.

```
 INPUT THE NAME OF THE C T  DATA BASE FILE
? ASSACT
```

The present values of the module input items are then displayed and the user is permitted to modify them as desired.

```
1
+          ASSA CONTIGUOUS BOX TRUSS

 CONTIGUOUS BOX TRUSS INPUT ITEMS

     17 680          1   RFDM   -RADIO FREQUENCY DIAMETER (METERS)
     1 0000          2   SHAPE  -SHAFE FLAG  1=PARABOLA  2=SPHERE, 3=FLAT
     1 0000          3   FOVERD -FOCAL LENGTH TO RF DIAMETER RATIO
    0                4   SODM   -MESH STAND-OFF DISTANCE (METERS)
    0                5   NMODE  -NUMBER OF MODE SHAPES (0=NO SAP MODELS)
    0                6   TUBTYP -STRUT TYPE  0=L/R  1=EULER, 2=ISOG  3=TRUSS
     8 8400          7   DEP    -BOX TRUSS DEPTH (METERS)
    0                8   FMESH  -MEMBRANE AXIAL FORCE FACTOR
    0                9   NFDS   -NUMBER OF FEED SUPPORT BEAMS
    5 00000E-03     10   AMNODE -CONCENTRATED MASS OF CORNER FITTING(KG)
    0               11   AMVER  -CONCENTRATED MASS OF VERTICAL HINGE(KG)
    0               12   AMHOR  -CONCENTRATED MASS OF HORIZONTAL HINGE(KG)
     1 0000         13   IFFIN  -PIN FLAG(0=NOT PINNED, 1=PINNED)
     2 0000         14   NBOXY  -NUMBER OF ROWS OF BOXES IN QUADRANT 1
     1 0000         15   NZHOR  -NUMBER OF HORIZONTAL TUBE PROPERTY ZONES
     2 0000         16   NZVER  -NUMBER OF VERTICAL TUBE PROPERTY ZONES
     1 0000         17   NZDIA  -NUMBER OF DIAGONAL TUBE PROFERTY ZONES
      10000         18   SURFDN -REFLECTOR MASS DENSITY(KG/SQ M)
     1 0000         19   SURTYP -REFLECTOR TYPE(1=MESH-2=ECMM)
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA THE KEYBOAPD
       2 TO ENTER A NEW TITLE
    OR 9 TO RETURN TO THE EXEC
? 0
```

The next set of input prompts is controlled by the value of item 14, the number of rows of box structures in the model. A prompt will be displayed requesting definition of the geometry for quadrant 1. The user must input the number of boxes for each row in quadrant 1 of the contiguous box truss structure until values have been provided for the number of rows specified. As an example, the following prompts and inputs correspond to the contiguous box truss structure of Figure 2.2.1.

```
 INPUT THE # OF BOXES FOR EACH ROW OF QUADRANT 1
 ROW  1
? 2
 ROW  2
? 1
```

After the number of boxes in each row of quadrant 1 have been specified, property zones may be defined. The user inputs the zone radius factor for each zone. In the test case there are: one horizontal, two vertical, and one diagonal property zones.

```
                 VERTICAL PROPERTY ZONE RADII


                        1             2
      ROW            RADIUS        RADIUS

        1           50000        4 0000
   ENTER 0 IF  INPUT IS OK
          1 TO CHANGE DATA ITEMS VIA THE KEYBOARD
          2 TO ENTER A NEW TITLE
      OR  9 TO RETURN TO THE EXEC
 ? 0
```

Completion of the property zone inputs results in entering the strucutral element size selection section. Each zone requires tube size input. For horizontal cylindrical tubes the user must specify the tube wall thickness and diameters of each end as follows.

```
                 HORIZONTAL TUBE DIMENSIONS(M)


                        1            2              3
      ROW       THICKNESS      DIAMETER

        1     2 50000E-03 5 00000E-02 5 00000E-02
   ENTER 0 IF  INPUT IS OK
          1 TO CHANGE DATA ITEMS VIA THE KEYBOARD
          2 TO ENTER A NEW TITLE
      OR  9 TO RETURN TO THE EXEC
 ? 0
```

For the vertical finned tubes the parameters required are the side length, wall thickness, fin length, and fin thickness. After the vertical tube sizes are defined the user must specify the diagonal tape cross sectional areas. These two sets of input parameters are as follows:

```
 |
 |        VERTICAL TUBE DIMENSIONS(M)


                     1              2              3              4
     ROW     FIN THICK     FIN LENGTH     WALL THICK     WALL LEN

        1     2 50000E-03 2 54000E-02 2 50000E-03 2 54000E-02
        2     3 50000E-03 3 54000E-02 3 50000E-03 3 54000E-02
  ENTER 0 IF  INPUT IS OK
         1 TO CHANGE DATA ITEMS VIA THE KEYBOARD
         2 TO ENTER A NEW TITLE
      OR 9 TO RETURN TO THE EXEC
 ? 0

  |         DIAGONAL  TAPE  AREA(M**2)


                     1              2              3
     ROW           AREA

         1     1 30000E-04 0              0
  ENTER 0 IF  INPUT IS OK
         1 TO CHANGE DATA ITEMS VIA THE KEYBOARD
         2 TO ENTER A NEW TITLE
      OR 9 TO RETURN TO THE EXEC
 ? 0
```

The final input matrix to be displayed permits selection of material properties. The properties required are Young's modulus, shear modulus, Poisson's ratio, and material density. The input format is:

```
1
+       MATERIAL PROPS  (1)HOR , (2)VER , (3)TOP DIAG , (4)LOWER DIAR                     PMATS  MATRIX

                1          2          3          4          5          6          7          8
   ROW        E          G          NU         RHO

     1   1 38000E+11 2 06000E+10   30000      1939 3     0          0          0          0
     2   1 38000E+11 2 06000E+10   30000      1939 3     0          0          0          0
     3   1 38000E+11 2 06000E+10   30000      1939 3     0          0          0          0
     4   1 38000E+11 2 06000E+10   30000      1939 3     0          0          0          0
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA THE KEYBOAPD
       2 TO ENTER A NEW TITLE
    OR 9 TO RETURN TO THE EXEC
7 0
```

After all inputs have been selected the module performs the functions necessary to create a dynamic model file and a mass properties matrices file. Successful generation of these files is indicated by display of the prompts:

```
 INPUT NAME DATA BASE FILE IS TO BE REPLACED AS
          (0 = DEFAULT (LASSDB)
? ASSACI
 INPUT NAME OF DYNAMIC MODEL FILE TO BE SAVED
? DYCI
 INPUT NAME OF MASS PROPERTIES MATRICES FILE
? MASSCI
```

The user inputs the name of a data base file, which can be the present file or a new file. Next, the dynamic model file name must be specified. This file contains the dynamic analysis program input data including GRID, CBAR, CROD, CONM2, and related records. After input of the dynamic model file the user must specify the name of the mass properties matrices file. This file contains the information necessary to calculate and/or modify the model mass properties in a subsequent execution of the Mass Properties Module. The final user input requested determines whether to terminate module execution or create another model.

```
 DO YOU WISH TO GENERATE ANOTHER CONTIGUOUS TRUSS MODEL
? NO
```

2.2.3 Contiguous Box Truss Module Programmer Information

This module is a revision of a quarter section model generator and has been extensively revised and has maintained the majority of original features. There are two primary overlays that are sectioned as input and initialization, model generation, and output. The code has been internally commented to facilitate revision. This section is then aimed at providing general information relevant to program modification or for interfacing with

other programs. The discussion will be sectioned to correspond to the primary overlays. The main overlay contains the calls to these primary overlays.

2.2.3.1 Overlay (1,0)

This overlay contains the input/output codes. The data statements contain variables, arrays, and headers necessary for communication with the data base file, dynamic model file, and mass properties matrices file. These data are found in subroutine BOXINPT. This subroutine contains some tests on critical input parameters. The maximum number of structural element types permitted is 10. This restricts the sum of the number of property zones (NZHOR, NZVER, NZDIA) to 10. If more zones are desired the test must be changed and the dimension of TUBP in COMMON/PROPS/increased by 14 for each additional zone or type desired.

The maximum number of bays allowed is controlled by the dimensions of GRIDD and IELM from COMMON/MASDAT/. At the present, a maximum of 300 nodes or 1250 structural elements are permissible. Creating a larger model will require increasing dimensions of one, or both, of these arrays. These arrays are used to transfer node coordinates and element connectivity information for model generation and. optionally, for plot file creation. Establishing connectivity through incore array search is much faster than searching through local files and was found necessary for models with a large numbers of bays.

2.2.3.2 Overlay (2,0)

This overlay contains the model generation code and associated subroutines. The original program from which this module was derived created only a quarter section model. Due to this, considerable time and effort has been expended to perform the necessary reflections to create a complete model. The grid identification numbers are sequenced based on quadrant location, location on top or bottom surface, row location, and column location. Nodes common to more than one quadrant are identified with the lowest common quadrant number.

The scheme for numbering bottom surface nodes may be seen in Figure 2.2.4. The top surface nodes differ only in the second digit. For example the bottom surface node number of 111112 corresponds to 121112 in the top surface.

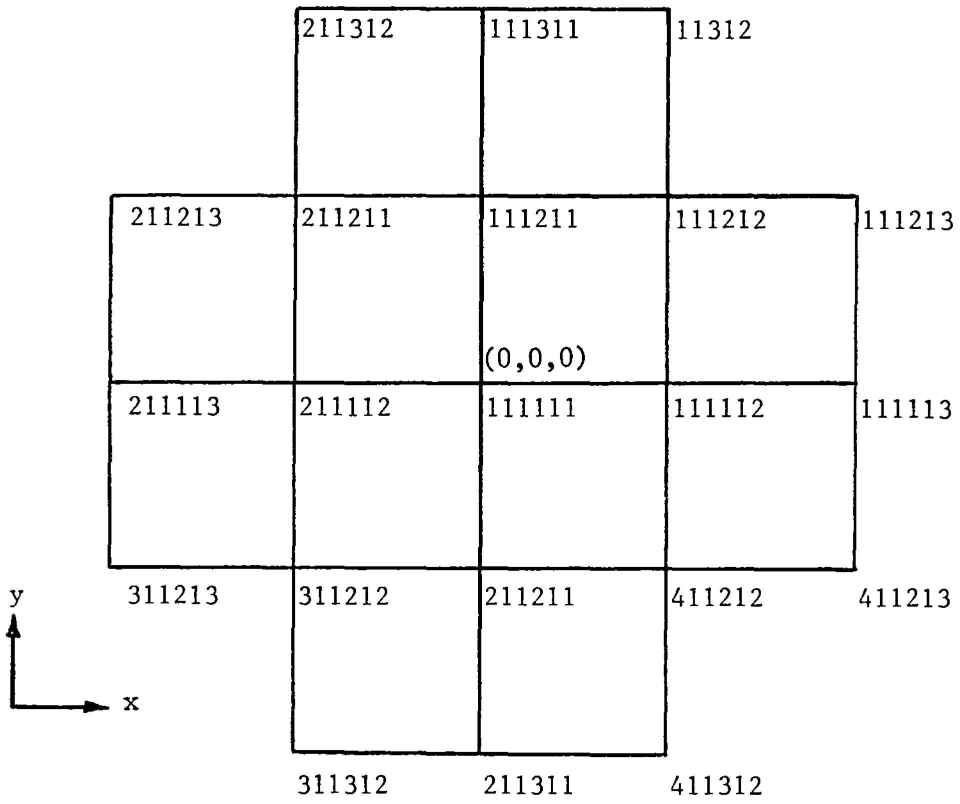


Figure 2.2.4. - Box truss numbering.

2.3 RADIAL RIB MODULE

The radial rib model generator automatically creates a NASTRAN-formatted bulk data input file, and generates the data for input into the Mass Properties module. The Mass Properties module performs the calculations necessary to define center of mass (c.m.) and inertias for the model.

2.3.1 Radial Rib Module Technical Description

Several types of radial rib configurations can be constructed using various components. The "basic" structure consists of a hub and ribs arranged axisymmetrically. To this may be added an external hoop that connects the rib tips and/or a central feed mast that may, on option, be supported by tension stays. The possible structural combinations that may be modeled with this module are shown in Table 2.3.1. Figure 2.3.1 shows a radial rib model with hoop, mast, and stays. Figure 2.3.2 shows node and element identification for two ribs of a model with a mast modeled with six segments.

TABLE 2.3.1. - RADIAL RIB STRUCTURAL COMBINATIONS.

Ribs	0	0	0	0	0	0
Hoop		0	0		0	
Mast			0	0	0	0
Stays					0	0

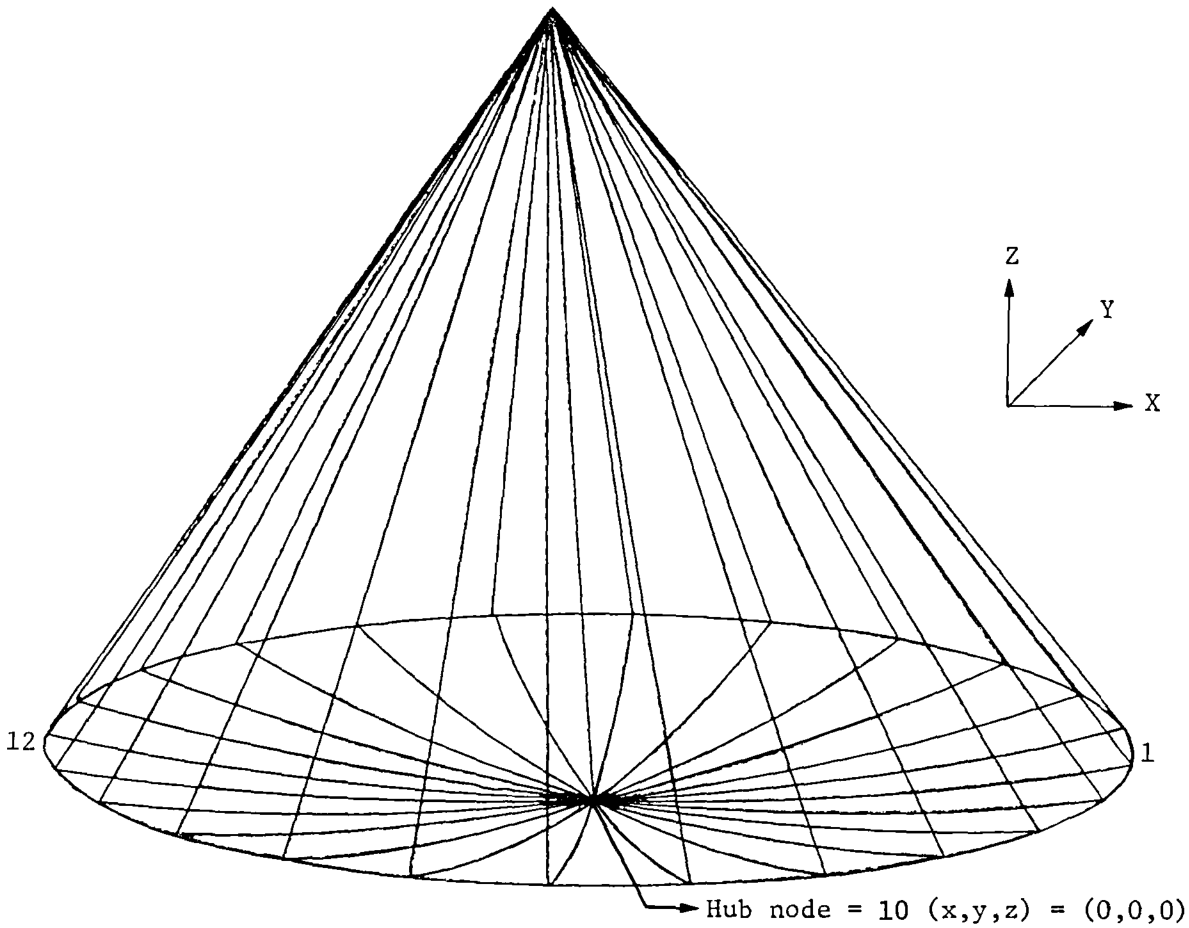


Figure 2.3.1. - Radial rib model with hoop, mast, and stays.

Figure 2.3.2. - Radial rib model node and element identification.

The assumptions inherent in the generation of data are as follows:

(1) Overall geometry is controlled by specification of diameter and focal length/diameter - these parameters define the equation for the parabolic reflecting surface;

(2) If a feed mast is included, it is assumed that the feed array lies at the focal point;

(3) If feed support stays are included, it is assumed that the feed array is connected to the tip of all ribs;

(4) If a hoop is included, it is assumed that it is connected to the tip of all ribs;

(5) All ribs are assumed to be identical and to have two cross-sectional planes of symmetry - the section properties need not be the same for both planes - rib properties are assumed to vary linearly from root to tip;

(6) The hoop, if included, is assumed to have constant cross-sectional properties with two planes of symmetry - section properties need not be the same for both planes;

(7) The feed mast, if included, is assumed to have two cross-sectional planes of symmetry - the section properties are assumed to vary linearly from root to tip;

(8) Feed array mass and hub mass are user specified;

(9) Reflecting surface mass/area is user specified - the appropriate mass distribution is "lumped" along the ribs - no stiffness of the reflecting surface is considered;

(10) The tension stay supports, if included, are assumed to be axial members (tension/compression).

The radial rib model coordinate system has the origin at the hub with positive z axis along the feed mast. Each rib is modeled using a series of BAR elements with decreasing cross-sectional area. The areas are weighted averages that depend on the position of the segment on the rib. The bending inertias and torsional inertias are similarly calculated as weighted averages for each BAR element. The feed mast properties are also calculated as weighted averages of properties at the tip and root. The concentrated mass of the feed array is assumed at the mast tip.

The grid coordinates and concentrated masses at grids are stored in array GRIDD. The concentrated masses on the rib nodes represent the distributed mass of the rf reflector surface. The hub mass is characterized as a concentrated mass at the (0,0,0) reference coordinate. Element connectivity information is stored in array IELM. Element properties are stored in array TUBP. These three arrays are written to a mass properties matrices file when leaving the module. Mass properties may be calculated, displayed, and modified as desired by subsequent execution of the Mass Properties Module using the mass properties and dynamic model files produced by the Radial Rib module. IELM contains connectivity data for the BAR elements (ribs, feed mast, hoop) and ROD elements (stays).

The dynamic model file produced is a NASTRAN formatted bulk data input deck that contains GRID, CONM2, BAR, ROD, PBAR, PROD, MAT1, SPC1, and GRAV cards. The last two record types provide added capability that may be selected from the NASTRAN case control. If not selected here, they will be ignored during a NASTRAN execution. If not used by SAP, the code generating them may be eliminated.

2.3.2 Radial Rib Module User Instructions

On entering the Radial Rib Model Generator module the user is asked to input the name of an input data base file by the prompt:

```
ENTER DATA BASE FILE NAME
   0 - DEFAULT NAME (LASSDB)
  PFN - PERMANENT FILE NAME

? ASSARIB
```

Next, the user selects the values of the input items necessary to define the radial rib structural configuration. The present program configuration requires that NSEG + IFHOOP + NFEEDS be less than 11. Increasing this capability is discussed in the following programmer section.

```
             ASSA RADIAL RIB TEST CASE


RADIAL RIB INPUT ITEMS

     100 00            1   RFDM    -RADIO FREQUENCY DIAMETER (METERS)
     1 0000            2   FOVERD  -FOCAL LENGTH TO RF DIAMETER RATIO
     24 000            3   NRIB    -NUMBER OF RIBS
     6 0000            4   NSEG    -NUMBER OF SEGMENTS PER RIB
     1 0000            5   IFHOOP  -FLAG TO INCLUDE HOOP (0=NO,1=YES)
     1 0000            6   IFFEED  -FLAG TO INCLUDE FEED MAST (0=NO,1=YES)
     1 0000            7   NFEEDS   NUMBER OF SEGMENTS ALONG FEED
     463 00            8   HUBMAS  -HUB MASS(KG)
      10000            9   SURFDN  -REFLECTING SURFACE MASS DENSITY
   1 00000E-02        10   GRAVEC  -SCALAR MULTIPLIER FOR GRAVITY VECTOR
ENTER 0 IF INPUT IS OK
      1 TO CHANGE DATA ITEMS VIA THE KEYBOARD
      2  TO ENTER A NEW TITLE
   OR 9 TO RETURN TO THE EXEC
? 0
```

After definition of these model parameters the user is prompted to select the rib properties from:

```
             ASSA RADIAL RIB TEST CASE


   RIB PROPERTIES
```

```
5 00000E-04      1   ARIBR   -RIB CROSS-SECTIONAL AREA AT ROOT(SQ M )
4 00000E-04      2   ARIBT   -RIB CROSS-SECTIONAL AREA AT TIP(SQ,M )
7 10000E-06      3   AIRB1R -RIB BENDING INERTIA, PLANE 1 AT ROOT
6 00000E-06      4   AIRB1T -RIB BENDING INERTIA, PLANE 1 AT TIP
5 30000E-06      5   AIRB2R -RIB BENDING INERTIA, PLANE 2 AT ROOT
1 00000E-06      6   AIRB2T -RIB BENDING INERTIA, PLANE 2 AT TIP
1 24000E-05      7   AJRIBR -RIB TORSIONAL INERTIA AT ROOT
7 04000E-06      8   AJRIBT -RIB TORSIONAL INERTIA AT TIP
7 00000E+10      9   RIBE    -YOUNG'S MODULUS FOR RIB
1 00000E+10     10   RIBG    -SHEAR MODULUS FOR RIB
  1939 3        11   RIBRHO -RIB MATERIAL DENSITY(KG/M**3)
ENTER 0 IF INPUT IS OK
      1 TO CHANGE DATA ITEMS VIA THE KEYBOARD
      2  TO ENTER A NEW TITLE
   OR 9 TO RETURN TO THE EXEC
? 0
```

If the user has defined a nonzero value for IFHOOP, the user next selects the hoop properties from:

```
              ASSA RADIAL RIB TEST CASE

  HOOP PROPERTIES

    4 48000E-04      1   AHOOP   -HOOP CROSS-SECTIONAL AREA
    9 63000E-07      2   AIHOOP1-HOOP BENDING INERTIA, PLANE 1
    1 04000E-05      3   AIHOOP2-HOOP BENDING INERTIA, PLANE 2
    1 14000E-05      4   AJHOOP -HOOP TORSIOONAL INERTIA
    7 00000E+10      5   HOOPE   -HOOP YOUNG'S MODULUS
    1 00000E+09      6   HOOPG   -HOOP SHEAR MODULUS
      1939 3         7   HOOPRHO-HOOP MATERIAL DENSITY
ENTER 0 IF INPUT IS OK
      1 TO CHANGE DATA ITEMS VIA THE KEYBOARD
      2 TO ENTER A NEW TITLE
   OR 9 TO RETURN TO THE EXEC
? 0
```

If the value of IFFEFD is not zero the feed properties are selected next from:

```
FEED & STAY PROPERITES

   2 00000E-05       1   AFEEDR -FEED CROSS-SECTIONAL AREA AT ROOT
   2 00000E-05       2   AFEEDT -FEED CROSS-SECTIONAL AREA AT TIP
   4 70000E-06       3   AIFEEDR-FEED BENDING INERTIA AT ROOT
   4 00000E-06       4   AIFEEDT-FEED BENDING INERTIA AT TIP
   1 38000E+11       5   FEEDE  -YOUNG'S MODULUS FOR FEED
   2 06000E+10       6   FEEDG  -SHEAR MODULUS FOR FEED
    1900 0           7   FEEDRHO-FEED MATERIAL DENSITY
    125 00           8   FEEDTIP-FEED ARRAY TIP MASS
   9 40000E-06       9   AJFEEDR-FEED TORSIONAL INERTIA AT ROOT
   8 00000E-06      10   AJFEEDT-FEED TORSIONAL INERTIA AT TIP
    1 0000          11   IFSTAY -FLAG TO INCLUDE STAYS(0=NO,1=YES)
   1 10000E-06      12   ASTAY  -STAY CROSS-SECTIONAL AREA
   1 30000E+12      13   STAYE  -YOUNG'S MODULUS FOR STAYS
   1 50000E+10      14   STAYG  -SHEAR MODULUS FOR STAYS
    1900 0          15   STAYRHO-STAY MATERIAL DENSITY
   0                16   AJSTAY -STAY TORSIONAL INERTIA
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA THE KEYBOARD
       2  TO ENTER A NEW TITLE
    OR 9 TO RETURN TO THE EXEC
? 0
```

If IFSTAY is zero the stay parameters will be ignored by the program. On completion of input definition the program executes, which results in generation of the geometry required for input into a dynamic analysis program. The next input requested is the name of the data base file that will contain the inputs selected on this execution.

```
INPUT NAME DATA BASE IS TO BE SAVED AS
? ASSARHF
ASSARHF
```

After input of the data base file name the user is requested to supply a name for the dynamic model file from:

```
INPUT DYMI FILE NAME
? DYMII
```

and finally for the name of the mass properties matrices file from;

```
INPUT NAME OF MASS PROPERTIES MATRICES FILE
? MASSRKH
```

At this point the user is prompted to generate a new model or to terminate exectuion of the Radial Rib Model Generator module.

2.3.3 Radial Rib Module Programmer Information

The Radial Rib module contains a main and three primary overlays. Overlay (1,0) contains the calls and logic to initialize required parameters and specify values of input variables. Labeled common WRIB contains the variables stored in the data base file specified during execution of this overlay. Labeled common HEADER contains the alphanumeric variable descriptions and variable names used during reads from, or writes to, the data base file. These alphanumeric data are loaded from the Block Data in the main overlay.

Overlay (2,0) performs the actual calculations and model generation. Models with up to 33 ribs with less than 10 segments per rib may be generated without modifying any program array sizes. If models with more elements are desired, the dimension of GRIDD and IELM must be changed. The 300 value for the GRIDD array corresponds to the maximum allowable number of node points in the model. The 1250 dimensions of IELM corresponds to the maximum allowable number of ROD and BAR elements. In addition, a constraint on the number of types of segments is inherent from the size of TUBP. Its present value (140) permits 10 different sets of element properties. Thus, if all model options (RIBS, FEED, HOOP, STAYS) are selected the maximum allowable number of rib segments will be six. Changing the size of TUBP will also require modification of the Mass Properties Module.

From overlay (2,0), the external calls of significance include subroutines SETELM and SETNOD. These subroutines load arrays GRIDD and IELM, which are subsequently used for mass properties and cost analysis. The variable ITYP used in the call to SETELM is assigned a different value for each rib segment,

and for any ROD or BAR elements created in the FEED, HOOP, or STAY sections. The value of ITYP is later used to define the element properties. The descriptions of key variables used in the overlay are included in program commentation. All required NASTRAN format records are written to local file TAPE2 during model creation.

The third primary overlay (3,0) contains the code required to create or update files and permit normal termination of execution. The data base file must be written first, followed by creation of the NASTRAN format dynamic model file. The last file created is the mass properties matrices file. The data base file uses a call to WRDTBS. The dynamic model file is created through a call to PFM. The mass properties matrices file uses an unformatted write to TAPE8 and a permanent file created through PFM.

2.4 HOOP AND COLUMN MODULE

The Hoop and Column Module generates a dynamic model input deck in NASTRAN format. The module interfaces with the Mass Properties Module for calculation and display of mass and inertia information.

2.4.1 Hoop and Column Module Technical Description

The "basic" structure consists of a central column and a circular hoop supported by fore stays that emanate from the hoop and terminate at the "feed" and by back stays that terminate at the "hub." Additionally, on user option, central stays (which lie approximately in the hoop plane) can be added. Any of the sets of tension stays may be arranged (on option) in a spoked (two stays/attachment point) configuration to provide hoop torsional stability. The possible combinations of these variables are as shown in Table 2.4.1:

TABLE 2.4.1. - HOOP/COLUMN MODEL GENERATOR OPTIONS.

Fore stays - single	0 0		0 0		0 0	
- spoked		0 0		0 0		0 0
Central stays - single			0 0			
- spoked					0 0	0 0
Back stays - single	0	0	0	0	0	0
- spoked	0	0	0	0	0	0

Figure 2.4.1 shows a typical hoop/column model. The hub node number is 101 and is located at the model origin (0,0,0). The column may be segmented above and below the hub with nodes increasing by 1 for each segment. Hoop node and element numbers start at 500 and increase in increments of 1 for each segment around the hoop. Lower stay numbers start at 12 000, central stays at 13 000, and upper stays at 14 000. Tiedown elements for surface shaping are not included in the model.

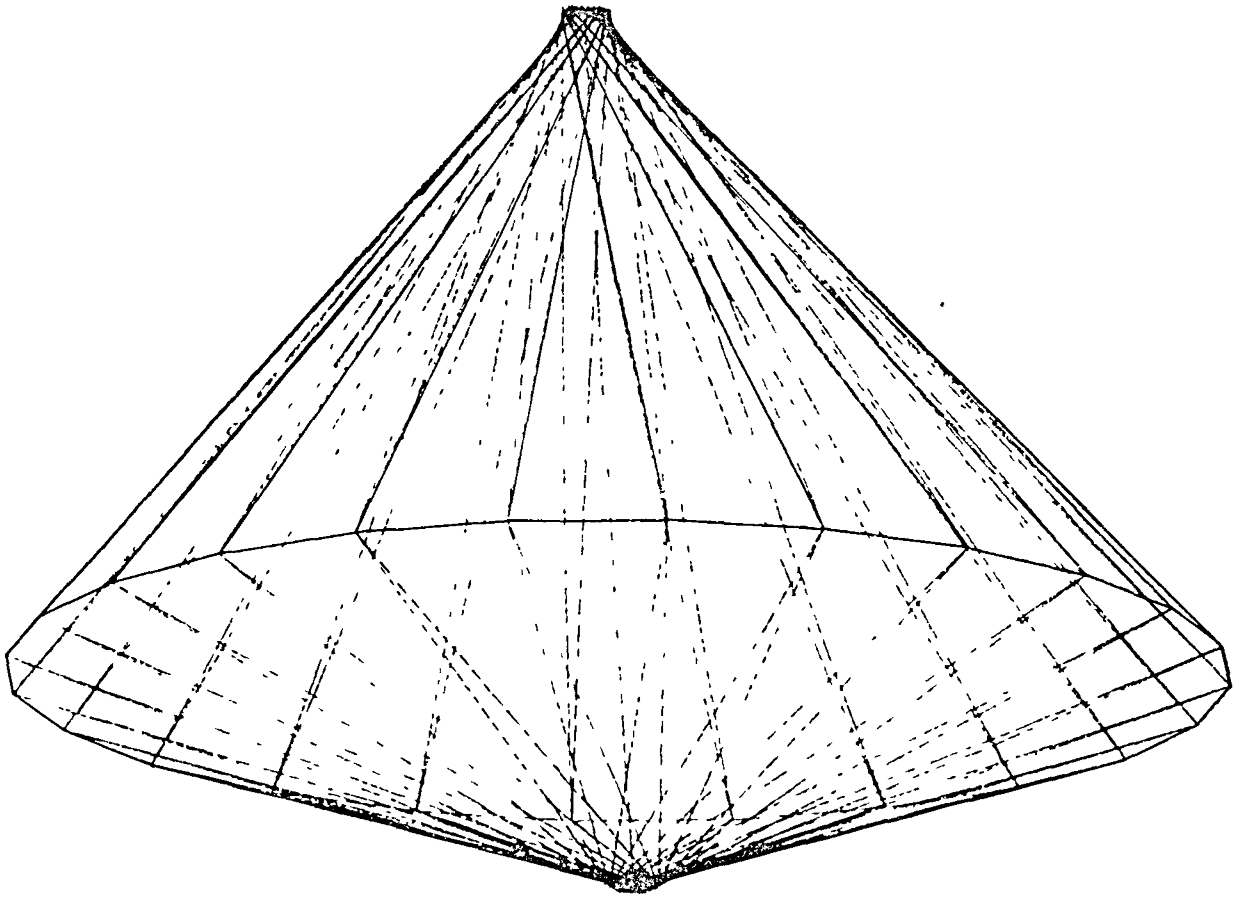


Figure 2.4.1. - Hoop and column configuration without central stays.

The assumptions inherent in the generation of data are as follows:

(1) Overall geometry is controlled by specification of hoop diameter, column length and column diameter at hub, central stay attachment point, and feed. This allows for a doubly tapered column;

(2) The column is assumed to have a doubly symmetric cross-section with constant material properties;

(3) The hoop is assumed to have two cross sectional planes of symmetry with constant material properties along the circumference;

(4) All stays in a given set (fore, central, back) are assumed to be identical. They are axial members (tension/compression);

(5) The reflecting surface has constant mass/area. Total surface mass is based on hoop area and is lumped around the hoop and at the central stay attachment point on the column (proportion determined by user input). No stiffness of the reflecting surface is considered;

(6) Feed array mass and hub mass are user specified.

The body coordinate system and component identification are similar to those of radial rib models described in section 2.3.

2.4.2 Hoop and Column Module User Instructions

When starting Hoop and Column Model generation the user is asked to input the name of the data base file containing the configuration data.

```
INPUT NAME OF HOOP/COLUMN DATA BASE FILE
? ASSAHC
```

Upon entering an appropriate file name the following geometry data and descriptions are displayed and the user prompted to accept or modify data. As with the other model generators the maximum number of element types is restricted to 10. This requires that the sum of NSEGL, NSEGU, and ISTAYC must be less than 8.

```
1
+             ASSA HOOP COLUMN TEST RUN

  HOOP/COLUMN MODEL DEFINITION

      1 0000          1  DB      -COLUMN DIAMETER AT BACK STAY/HUB ATTACH POINT(M)
       50000          2  DC      -COLUMN DIAMETER AT CENTRAL STAY ATTACH POINT(M)
      1 0000          3  DF      -COLUMN DIAMETER AT FORE STAY/FEED ATTACH POINT(M)
      30 000          4  HC      -HEIHGT OF CENTRAL STAY ATTACH POINT ABOVE HUB(M)
      100 00          5  HF      -HEIGHT OF FEED ABOVE HUB(M)
      25 000          6  HH      -HEIGHT OF HOOP ABOVE HUB(M)
      100 00          7  DH      -HOOP DIAMETETER(M)
      3 0000          8  NSEGL   -NUMBER OF SEGMENTS ALONG LOWER PORTION OF COLUMN
      3 0000          9  NSEGU   -NUMBER OF SEGMENTS ALONG UPPER PORTION OF COLUMN
      24 000         10  NSEGH   -NUMBER OF HOOP SEGMENTS
      1 0000         11  ISTAYC -FLAG TO INDICATE CENTRAL STAYS(0=NO, 1=YES)
       10000         12  SURFRHO-REFLECTING SURFACE MASS/AREA(KG/SQ M)
       70000         13  SURFALP-PERCENT TOTAL SURFACE MASS LUMPED AROUND HOOP
      1000 0         14  HUBMASS-HUB MASS(KG)
      300 00         15  FEEDTIP-FEED ARRAY TIP MASS(KG)
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD
       2 TO ENTER A NEW TITLE
    OR 9 TO RETURN TO THE EXEC
? 0
```

The next set of data permits user definition of column properties from:

```
1
+             ASSA HOOP COLUMN TEST RUN

  COLUMN PROPERTIES

       10000          1  ACOLB   -COLUMN CROSS-SECTIONAL AREA AT HUB(SQ M)
      1 2500          2  AICOLB -BENDING INERTIA AT HUB(M**4)
      2 5000          3  AJCOLB -TORSIONAL INERTIA AT HUB(M**4)
       20000          4  ACOLC   -C-S AREA AT CENTRAL STAY ATTACH(SQ M)
       20000          5  AICOLC -BENDING INERTIA AT CENTRAL STAY ATTACH(M**4)
       40000          6  AJCOLC -TORSIONAL INERTIA AT CENTRAL STAY ATTACH
       10000          7  ACOLF   -C-S AREA AT FEED(SQ M)
      1 2500          8  AICOLF -BENDING INERTIA AT FEED
      2 5000          9  AJCOLF -TORSIONAL INERTIA AT FEED
    1 32000E+11      10  COLE    -YOUNG'S MODULUS
    1 51000E+10      11  COLG    -SHEAR MODULUS
      1900 0         12  COLRHO -DENSITY(KG/CU M)
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD
       2 TO ENTER A NEW TITLE
    OR 9 TO RETURN TO THE EXEC
? 0
```

Next the user must specify the hoop properties data from:

```
1
+             ASSA HOOP COLUMN TEST RUN

  HOOP PROPERTIES

    4 50000E-03      1  AHOOP   -HOOP C-S AREA(SQ M)
    9 60000E-06      2  AIHOOP1-BENDING INERTIA IN HOOP PLANE
    1 07000E-05      3  AIHOOP2-BENDING INERTIA IN PLANE NORMAL TO HOOP PLANE
    1 21000E-05      4  AJHOOP -TORSIONAL INERTIA
    7 01000E+10      5  HOOPE   -YOUNG'S MODULUS
    1 01000E+10      6  HOOPG   -SHEAR MODULUS
     2000 0          7  HOOPRHO-DENSITY(KG/CU M)
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD
       2 TO ENTER A NEW TITLE
    OR 9 TO RETURN TO THE EXEC
? 0
```

With the next set of data the user defines the stay and spoke configuration. If the value of ISTAYC is set to zero the central stay properties will be ignored by the program. The stay and spoke data prompts are:

```
1
+         ASSA HOOP COLUMN TEST RUN

 FORE AND BACK STAY PROPERTIES

    0              1  ISPOKF -FLAG TO INDICATE SPOKED(0=NO, 1=YES)
    1 10000E-06    2  ASTAYF -FORE STAY AREA (SQ M)
    0              3  AJSTAYF-FORE STAY TORSIONAL INERTIA(M**4)
    1 30000E+11    4  STAYEF -YOUNG'S MODULUS(NT/SQ M)
    1 50000E+10    5  STAYGF -SHEAR MODULUS(NT/SQ M)
     1909 0        6  STAYROF-DENSITY(KG/SQ M)
     1 0000        7  ISPOKB -FLAG TO INDICATE SPOKED(0=NO, 1=YES)
    1 10000E-06    8  ASTAYB -BACK STAY AREA(SQ M)
    0              9  AJSTAYB-TORSIONAL INERTIA(M**4)
    1 38000E+11   10  STAYEB -YOUNG'S MODULUS(NT/SQ M)
    2 30000E+10   11  STAYGB -SHEAR MODULUS(NT/SQ M)
     1939 0       12  STAYROB-DENSITY(KG/SQ M)
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD
       2 TO ENTER A NEW TITLE
    OR 9 TO RETURN TO THE EXEC
? 0
1

+         ASSA HOOP COLUMN TEST RUN

 CENTRAL STAY PROPERTIES

     1 0000        1  ISPOKC -FLAG TO INCLUDE CENTRAL STAYS(0=NO, 1=YES)
    1 10000E-06    2  ASTAYC -CENTRAL STAY AREA(SQ M)
    0              3  AJSTAYC-TORSIONAL INERTIA(M**4)
    1 38000E+11    4  STAYEC -YOUNG'S MODULUS
    2 30000E+10    5  STAYGC -SHEAR MODULUS
     1939 0        6  STAYROC-DENSITY(KG/SQ M)
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD
       2 TO ENTER A NEW TITLE
    OR 9 TO RETURN TO THE EXEC
? 0
```

Definition of these data results in execution of the module. Successful execution is indicated by the prompt requesting user input of the Data Base file name as follows.

```
 NAME DATA BASE IS TO BE SAVED AS
? ASSAHC
```

```
 NAME OF DYNAMIC MODEL FILE
? DYHC
```

```
 NAME OF MASS PROPERTIES MATRICES FILE
? MASSHC
```

2.4.3 Hoop and Column Module Programmer Information

This module contains a main overlay (0,0) and two primary overlays, (1,0) and (2,0). The (0,0) overlay functions primarily to call the secondary overlays as required. The (1,0) overlay performs the initialization, input, and output operations while the (2,0) overlay performs model generation. Overlay (1,0) performs input and initialization functions when flag ICASF = 1 and performs output functions when ICASF = 2. If the input sequence is terminated ICASF is set to 4 before return to the main overlay. The subroutines used for input/output operations are contained in libraries AVIDLIB and LASSLIB.

Overlay (2,0) contains the code required to generate the model geometry, dynamic model file, and mass properties matrices in forms that are similar to other model generators. All key variables are identified by commentation in program HCCALC. Subroutines SETNOD and SETELM are contained in the overlay. They create the node and element matrices for subsequent mass properties file definition.

2.5 MASS PROPERTIES MODULE

The Mass Properties Module calculates mass properties of structural models created by the automated model generators. In addition, the module permits the user to add or delete masses representing auxiliary equipment, which permits interactive determination and iteration of spacecraft mass properties. The module outputs include the mass properties data required for subsequent analyses (e.g. controls, orbital transfer) and an updated input file for dynamic analysis.

2.5.1 Mass Properties Module Technical Description

The model generators that interface with the Mass Properties Module include the Box Ring, Radial Rib, Hoop and Column, and Contiguous Box Truss modules. These modules create a mass properties matrices file, which contains the grid, element, and element properties data required for mass properties

definition. These data are read at the start of execution of this module. The concentrated masses of the end fittings and midlink hinges (for truss-type structures) are retrieved from the structural model data base.

If any of the nodes' concentrated masses are to be changed (to represent location of subsystem's components) the mass properties matrices file and dynamic model file will be regenerated to reflect these changes. After changing concentrated masses, the calculation of total mass, center of mass (c.m.), and inertia properties are started. Each concentrated mass is multiplied by its appropriate X, Y, and Z coordinates to obtain $\sum M\vec{r}$ and the masses are summed to determine total mass from all concentrated masses. The masses of tubes and their effect on inertias are determined from tube area, length, material density, and coordinates of the tubes' midpoints. It is assumed that the mass of a tube is concentrated at its midpoint.

The masses of nodes defined in model generators include the distributed mass of the reflective mesh or membrane. The total mass of the reflector is obtained by subtracting the total mass of all end fittings from total mass of nodes-concentrated mass. The concentrated masses enter through array CRIDD as item (n,5) where the range of n is from 1 to NG, the number of grids in the model. For nontruss models (e.g., radial rib) the concentrated mass includes only the reflective surface and the central hub mass.

2.5.2 User Instructions

The Mass Properties Module performs the calculations necessary to determine the center of mass (c.m.), total spacecraft mass component masses, and inertias for LSS structural geometries defined by model generator modules. On execution of this module, the user is requested to input the name of the data base file that contains the structural model parameters.

```
INPUT NAME OF STRUCTURAL MODEL DATA BASE FILE
? GK29BOX
```

The parameters required for execution of the Mass Properties Module are then displayed as:

```
|
|           MASS PROPERTIES DEFINITION


 MASS PROPERTIES STRUCTURAL DEFINITION

     103 00           1  RFDM    -RADIO FREQUENCY DIAMETER (METERS)
     2 0000           2  FOVERD -FOCAL LENGTH TO RF DIAMETER RATIO
      90800           3  AMNODC  -END FITTING MASS(KG)
   0                  4  AMHING -TUBE HINGE MASS(KG)
 ENTER 0 IF INPUT IS OK
       1 TO CHANGE DATA ITEMS VIA KEYBOARD,
       2 TO ENTER A NEW TITLE,
    OR 9 TO RETURN TO THE EXEC
 ? 0
```

The next two prompts request input of the mass properties matrices file and the dynamic model file, which were defined during execution of the model generator module or Appendage Synthesizer.

```
INPUT NAME OF MASS PROPERTIES MATRICES FILE
? MASSASSA
```

```
INPUT NAME OF DYNAMIC MODEL FILE
? DYASSA
```

At this point the user has the option of modifying the model by adding or deleting concentrated masses at existing nodes by answering "YES" to the prompt:

```
DO YOU WISH TO CHANGE DISCRETE MAS(ES)
? Y
```

If mass changes are requested, the user is asked whether a listing of nodes is desired. The prompt is:

```
DO YOU WISH TO LIST GRID IDS AND MASSES (Y OR N)
? Y
```

If it is desired to list nodes, they will appear in the form shown as follows, 20 nodes maximum per display.

GRID ID	X, Y, Z COORDINATES (METERS)			MASS (KG)
101	0 00	60 00	14.00	9080
102.	13.35	58 50	14 00	9080
103.	26 03	54.06	14.00	9080
104	37.41	46.91	14.00	9080
105	46.91	37.41	14 00	9080
106	54 06	26 03	14.00	9080
107	58.50	13.35	14.00	9080
108.	60 00	00	14.00	9080
109	58.50	-13.35	14.00	9080
110	54.06	-26.03	14.00	9080
111.	46 91	-37.41	14.00	.9080
112.	37 41	-46 91	14.00	9080
113	26.03	-54.06	14.00	9080
114	13 35	-58 50	14.00	.9080
115	00	-60.00	14.00	.9080
116.	-13.35	-58.50	14.00	9080
117	-26.03	-54.06	14 00	.9080
118.	-37 41	-46.91	14.00	9080
119.	-46 91	-37 41	14.00	.9080
120.	-54 06	-26.03	14.00	.9080

```
MORE (<RETURN> - YES, ANY LETTER - NO)
? N
```

The user then is asked to input the node number, where a discrete mass will be modified and also the new mass.

```
ENTER GRID ID, A COMMA, AND NEW MASS (KG)
(ENTER 0,0 TO STOP)
? 101,27 908

? 0,0
```

```
DO YOU WISH TO LIST GRID IDS AND MASSES (Y OR N)
? Y
```

GRID ID	X, Y, Z COORDINATES (METERS)			MASS (KG)
101	0.00	60.00	14.00	27.9080
102	13 35	58.50	14 00	9080
103.	26 03	54.06	14 00	9080
104	37 41	46.91	14.00	9080
105.	46 91	37.41	14 00	9080
106	54 06	26.03	14 00	9080
107	58.50	13.35	14.00	9080
108.	60.00	.00	14 00	9080
109	58 50	-13 35	14.00	9080
110.	54.06	-26.03	14.00	9080
111	46.91	-37.41	14.00	9080
112.	37.41	-46.91	14.00	9080
113.	26.03	-54 06	14.00	9080
114	13.35	-58.50	14 00	9080
115.	.00	-60 00	14.00	9080
116.	-13 35	-58 50	14.00	9080
117.	-26.03	-54.06	14.00	9080
118	-37 41	-46.91	14 00	9080
119	-46 91	-37.41	14.00	9080
120	-54.06	-26.03	14 00	9080

At this point, the program automatically regenerates the mass properties matrices and dynamic model files via the prompts:

```
ENTER NAME FOR UPDATED MASS PROPS  FILE ( 7 CHARACTERS MAX )
? MASASSA

ENTER NAME FOR UPDATED DYNAMIC MODEL ( 7 CHARACTERS MAX )
? DYASSA
```

The mass properties are now calculated and displayed in the following form:

```
MASS PROPERTIES DEFINITION


CENTRE OF MASS COORDINATES  XCM=    12189E+01
                            YCM =  - 10737E+00
                            ZCM =    24205E+02


TOTAL S/C MASS(KG)=    52261E+04
MASS OF RF REFLECTOR AND AUXILIARY EQUIPMENT =,    39957E+04

MASS OF  114 ENDFITTINGS =    10351E+03
MASS OF   56 TYPE  1 TUBES =    21303E+03
MASS OF   56 TYPE  2 TUBES =    16031E+03
MASS OF   56 TYPE  3 TUBES =    10062E+03
MASS OF   56 TYPE  4 TUBES =    38162E+03
MASS OF  280 TYPE  5 TUBES =    21272E+03
MASS OF    1 TYPE  6 TUBES =    28963E+02
MASS OF    1 TYPE  7 TUBES =    69232E+00
MASS OF    1 TYPE  8 TUBES =    28963E+02


INERTIA PROPERTIES
          XXM =    16160E+08
          YYM =    15202E+08
          ZZM =    14640E+08
          PXY =    26323E+05
          PXZ =    89179E+05
          PYX =  - 78560E+04
```

2.5.3 Mass Properties Module Programmer Information

The Mass Properties Module consists of a main and three primary overlays. There are four labeled common blocks that contain the variables and arrays required for module calculations. MASSIN contains data variables brought in through access to the structural model data base file. MASDAT contains the arrays accessed in the mass properties matrices file. PROPS contains 14 properties for up to 10 different types of BAR or ROD structural elements. MASPR contains the mass and inertia properties calculated during module execution.

Primary overlay (1,0) contains the code required for initialization and termination. The variable ICASE in labeled common FLAGS is used to select either the input or output section of this overlay. If ICASE equals 1 initialization and input mode is entered. For ICASE equal to 2 the output mode

is entered. Overlay (1,0) contains DATA statements to define alphanumeric data used for description of input data and for writing to the data base file. The output section also controls display of mass properties informaion.

Overlay (2,0) contains the code that determines the basic mass and inertia properties. A maximum of 10 element property sets is currently allowed. If more should be required, the dimension of array TUBP must be increased. TUBP contains 10 sets of 14 properties. The properties used in this module are the cross-sectional area (1 in each set) and the material density (8 in each set).

The first operation involves extraction of the reflector and end fitting or hub masses from the concentrated mass records stored in GRIDD (N,5). These calculations are performed through a sequential call to subroutines SURMASS and MASMAT. SUPMASS controls iteration through all grid points. MASMAT calculates the summation of discrete mass times distance from the origin (0,0,0) as SX, SY, and SZ. The total mass due to grid masses, X, Y, and Z inertias, and inertia products are also summed in MASMAT. Each grid in the model requires a call to MASMAT. The end fitting mass for truss models is contained in variable AMNODE. For nontruss models AMNODE will be zero. At exit from SUPMASS the total reflector mass (RFFMAS) and end fitting mass (GMAS) will be defined.

The next set of mass contributions to be determined are for midlink hinges. All elements are interrograted for type (IELM (1,N)). Tubes that fold have a type number greater than 10. For these tubes the hinge mass (AMHING from the structural model) is used to determine contribution to total mass and inertias. The hinge is assumed at the tube midpoint coordinates.

The final mass properties calculations are performed in subroutine TUBMAS. The arrays IELM, GRIDD, and TUBP are used to obtain each element area, length, density, and mass. Each different type of tube and the cumulative mass of that type are stored in arrays NTUB and TUBMAS respectively. The last step in this overlay is calculation of the center of mass coordinates.

Overlay (3,0) provides the capability of modifying masses at grid points. Masses representing auxiliary equipments may be added, deleted, or located at different nodes. Considerable commentary is provided in the code and will not be repeated here. If masses are modified the dynamic model file (TAPE2) is searched for appropriate CONM2 records and the record changed to reflect the new mass. Each record, whether changed or not, is written in the same format as TAPE3. After all changes are made TAPE3 is written as a new dynamic model file using subroutine PFM. Similarly, any modified masses are reflected in a change to array GRIDD (n,5). A new mass properties matrices file is generated by writing IELM, GRIDD, NEL, NG, and TUBP to TAPF8 and then to a permanent file again using PFM. After executing this section, control passes to overlay (2,0) to calculate mass properties.

2.6 ORBITAL TRANSFER MODULE

This module uses user-specified initial and final orbital altitudes, initial and final inclination angles, and spacecraft mass to calculate propulsion requirements for a Hohmann transfer and a 3-impulse optimal plane change maneuver.

2.6.1 Orbital Transfer Module Technical Description

The orbital transfer program provides a means for assessing various propulsion systems, evaluated according to mission requirements. Inputs to the program consist of mission transfer requirements and propulsion system data. One set of output variables will be produced for each set of propulsion system variables used.

The program considers the Hohmann type transfer between two circular orbits of radii r_1 and r_2 with $r_1 < r_2$. This type of transfer represents the minimum total ΔV required. A two impulse or three impulse bielliptical transfer is selected depending on the ratio of the initial and final orbit altitudes. If this ratio (r_2/r_1) is greater than about 11.8, the bielliptical transfer will be more economical. The following equations are taken from reference 6.

In the classical two burn maneuver, the initial impulse is applied tangentially to the initial circular orbit. This injects the spacecraft on a transfer ellipse with sufficient velocity to reach the desired orbit. The magnitude of ΔV, is given by:

$$\Delta V_1 = \sqrt{\frac{\mu}{r_1}} \left[\frac{2(r_2/r_1)}{1 + (r_2/r_1)} \right]$$

where:
r_1 = radius of lower initial orbit
r_2 = radius of higher final orbit
μ = constant defined by G and mass of the earth.

The second velocity ΔV_2 is obtained by the conservation of angular momentum at points r_2 and r_1 or $h = r_1 v_1 = r_2 v_2$. This gives a value of ΔV_2 as:

$$\Delta V_2 = \sqrt{\frac{\mu}{r_2}} \left[1 - \frac{2}{1 + (r_2/r_1)} \right]$$

The total velocity requirement $\Delta V_T = \Delta V_1 + \Delta V_2$.

The bielliptical transfer consists of three velocity impulses ΔV_1, ΔV_2, ΔV_3. The initial burn is applied to attain, after a 180° transfer, an intermediate point. At this point another burn ΔV_2 is applied to transfer the spacecraft to the desired orbit, and a final burn ΔV_3 is used to circularize the orbit. Using the same methods as for the two impulse transfer a rather lengthy relationship is derived.

$$\frac{\Delta V_1+\Delta V_2+\Delta V_3}{V_0} = \sqrt{\frac{2R_{21}}{1+R_{21}}} - 1 + \sqrt{\frac{2}{R_{21}}}\left[\sqrt{\frac{R_{31}}{R_{31}+R_{21}}} - \frac{1}{\sqrt{1+R_{21}}}\right] + \frac{1}{\sqrt{R_{31}}}\left[\frac{2R_{21}}{R_{21}+R_{31}} - 1\right]$$

where: R_{21} = intermediate point(R_2)/ initial orbit (R_1)
R_{31} = final altitude (R_3)/ initial orbit
V_0 = initial orbit velocity $\sqrt{\frac{\mu}{R_1}}$

The intermediate value R_{21} is an optimization problem constrained by the boundary conditions R_3 and R_1. The derivatives for this optimization and the resulting equation for R_{21} are contained in the program and R_{21} is calculated. In this treatment the propulsive requirements to effect the ΔV_T assumes impulsive burns and unperturbed Keplerian motion. The effects of finite burning time are not included.

2.6.2 Orbital Transfer Module User Instructions

On entry the user is prompted to specify the initial altitude (km), the desired final altitude (km), the initial inclination angle (deg), the final inclination angle (deg), and the dry spacecraft mass.

```
 INITIAL S/C ALTITUDE IN KM
? 278

 FINAL ALTITUDE IN KM
? 650

 CHANGE IN INCLINATION ANGLE IN DEG.
? 0

 TOTAL DRY S/C MASS IN KG
? 5226

 ISP OF PROPULSION ENGINE IN LBF-SEC/LBM
? 230
```

The program then calculates and outputs the total spacecraft and propellant mass required.

```
DELTA V FOR ORBIT CHANGE IN M/SEC------   .20787E+03
TOTAL WET S/C MASS IN KG---------------   .57305E+04
TOTAL PROPELLANT MASS IN KG--   .50452E+03
```

The user is then prompted to terminate module execution or to perform another analysis.

```
 DO YOU WISH TO RUN ANOTHER CASE
? NO
```

2.6.3 Orbital Transfer Module Programmer Information

The program does not require overlays as it now exists. If other propulsion requirement calculation algorithms are to be added they must interface with the following variables.

HIN - initial altitude (m)
FALT - final altitude (m)
INCLIN - initial inclination (deg)
INCLOUT - final inclination (deg)
SCMASS - total spacecraft mass (kg)
I_{sp} - specific impulse of engine (lb_f-sec/lb_m)

2.7 RF ANALYSIS MODULE

The rf analyses performed for this contract were detailed analyses and the software is not consistent with interactive techniques. The code in this module includes an algorithm developed to determine the rms surface distortion (ZRMS) of the ECMM baseline design (ref. 2) and a simple calculation of gain degradation for the calculated surface distortion.

2.7.1 Rf Module Technical Description

The Ruze equation is used to determine the loss of an antenna due to random surface roughness. It assumes a small correlation distance (small with respect to reflector diameter). The loss is determined from equation (3), where δ is rms roughness and λ is wavelength with consistent units for both.

$$\text{Loss} = e\left[-\left(4\pi\frac{\delta}{\lambda}\right)^2\right] \tag{3}$$

The loss in dB is given by:

$$\text{dB} = 686\left(\frac{\delta}{\lambda}\right)^2$$

The surface calculations performed by program RFSURF are for the ECMM baseline surface design and are discussed in detail in reference 2. The equation developed to model the surface distortion at a point is:

$$\delta(x,y) = (0.17 + 0.03\ \mathrm{DARC/R})\ \mathrm{SIN}\ [\pi\sqrt{2}\ \mathrm{XARC/DF}]\ \mathrm{SIN}\ (\pi\sqrt{2}\ \mathrm{YARC/DF}) \qquad (4)$$

where: $\delta(X,Y)$ is Z distortion from ideal surface at point (X,Y) (cm)

R is aperture radius (cm)

DARC is are length from surface vertex to point (cm)

DF is deformation grid spacing (cm)

XARC, YARC are arc lengths from vertex to X,Y grids (cm)

The (X,Y) distortions are used to calculate Z rms by iterating over a grid whose spacing is defined as 0.75 of the wavelength in question. Figure 2.7.1 shows the ECMM surface model. For a frequency of 5 GHz this requires about 1 million points to analyze the normal ECMM aperture of 50 meters. If a smaller aperture is selected for analysis the number of points required is decreased exponentially. For example, decreasing the illuminated aperture by 1/2 will require 1/4 as many points. In order to execute, the specified aperture diameter may not be less than 10 meters. The electrode spacing and frequency may then be varied to determine rms distortion; however, it must be noted that execution time will exceed 10 minutes, which is inconsistent with most interactive environments.

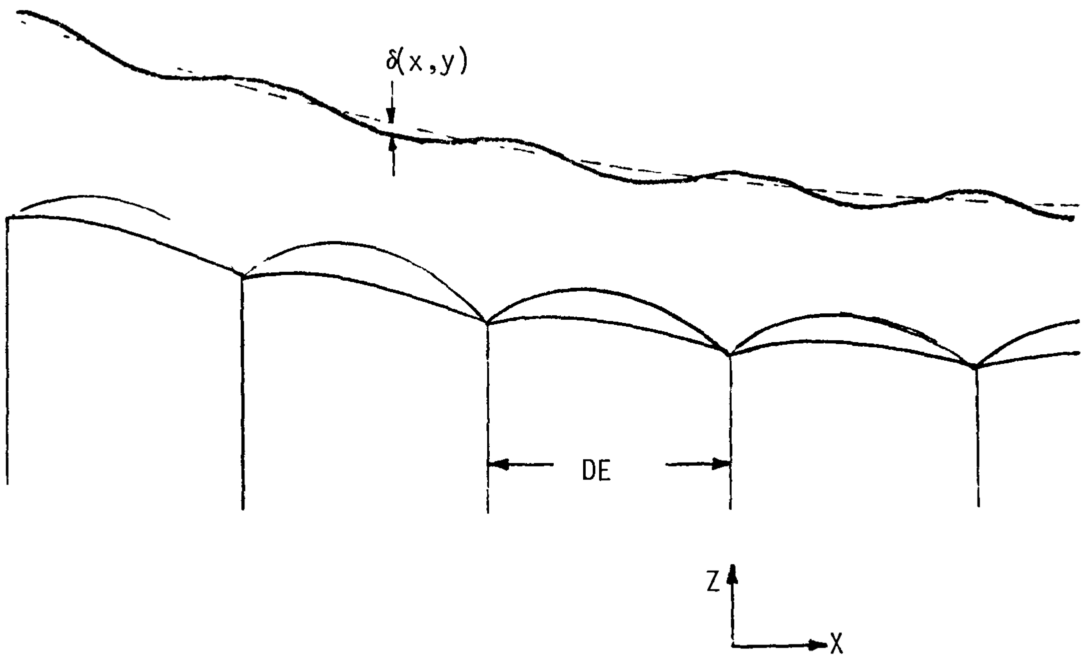


Figure 2.7.1. ECMM Surface Model

2.7.2 Rf Module User Instructions

The inputs required are the reflector radius of curvature in meters illuminated spot diameter in cm, ECMM electrode spacing in cm, and operating frequency for which gain loss is to be determined. The user interaction will appear as follows. After calculation the output will be displayed as shown. The user is then prompted to perform another analysis or terminate module execution.

```
ASSA ECMM SYSTEMATIC DISTORTION DUE TO ELECTRODES AND TIES


 INPUT REFLECTOR RADIUS OF CURVATURE (M)
? 200
 INPUT ILLUMINATED SPOT DIAMETER(CM)
? 1000
 INPUT ELECTRODE SPACING (CM)
? 500
 INPUT RF FREQUENCY(GHZ)
? 4.95
```

MAIN BEAM GAIN LOSS FROM RUZE EQUATION

ZRMS(CM)	FREQ(GHZ)	LOSS(DB)
.11988E+00	.49500E+01	.26839E+00

2.7.3 Rf Analysis Module Programmer Information

The gain loss calculation is performed in subroutine RUZE. This loss depends on the frequency being considered (FREQ) and the rms distrotion (ZRMS) in cm. Presently, the call to RUZE is from program RFSURF. If it is desired to perform the calculation for a surface other than the FCMM, then RFSURF must be replaced or bypassed. The new calling program must supply a value for FREQ and ZRMS through: COMMON/RFINPT/ZRMS, FREQ(5), DBLOSS(5).

DBLOSS will contain the gain loss in dB for the corresponding input frequency.

2.8 RIGID BODY CONTROLS (RCD) MODULE

The LASS RCD module has been modified to include effects of solar pressure on vehicle attitude. Additionally, the atmospheric density model and its implementation have been changed. The module can be run in its original mode with no input or output variations. A new mode, designated "stand-alone" has been implemented. Following are the technical approach, user instructions, and programmer documentation relating to standalone operation.

2.8.1 PCD Module Technical Description

The spacecraft to be analyzed is assumed in a circular orbit, subjected to environmental and vehicle interaction forces and torques without an ACS on board. Orbital velocity is assigned to the x-axis. The following development and approach is coded into the stand-alone related code. This code is not, at present, capable of automatically interfacing with the existing automated model generators. It is primarily intended for analysis of the spacecraft identified and described in reference 2.

2.8.1.1 Symbols

The symbols employed in this section are defined as follows:

$\vec{T}_{GG}$	Gravity gradient torque, N-m;
$\vec{T}_S$	Solar radiation pressure torque, N-m;
$\vec{T}_A$	Aerodynamic torque, N-m;
$\vec{T}_{INA}$	Vehicle interaction torque, N-m;
$\vec{T}_T$	Total torque exerted on the vehicle, N-m;
$\vec{T}_E$	Total of external torques exerted on the vehicle due to the environment, N-m;
$\vec{F}_S$	Solar radiation pressure force, N;
$\vec{F}_A$	Aerodynamic force, N;
$\vec{H}_I$	Angular momentum relative to inertial space, N-m-s;
$\vec{H}_V$	Angular momentum relative to vehicle, N-m-s;

$\vec{w}_{vI}$	Angular velocity of the vehicle relative to inertial space, rad/s;
$\vec{w}_{RI}$	Angular velocity of the rotating reference frame relative to inertial space, rad/s;
$\vec{w}_{vR}$	Angular velocity of the vehicle relative to the rotating reference frame, rad/s;
$\vec{w}_o$	Orbital rate, rad/s;
$[I]$	Inertia matrix;
R_o	Radius vector from center of the earth to the orbit, km;
R_e	Radius of the spherical Earth, km;
h	Orbit altitude, km;
x,y,z	Vehicle frame axis system;
x_R,y_R,z_R	Rotating reference frame axis system;
x_I,y_I,z_I	Inertial frame axis system;
n	Anomaly angle, ($w_o t$) degrees;
θ,ϕ,ψ	Euler angles, radians;
t	Time, sec.

2.8.1.2 Rigid Body Equations of Motion

The rotational motion of the rigid vehicle is described by:

$$\vec{T}_E = \frac{d\vec{H}}{dt} = [I]\dot{\vec{\omega}}_{VI} + [\dot{I}]\vec{\omega}_{VI} + \vec{\omega}_{VI} \times [I]\vec{\omega}_{VI} \tag{5}$$

where [I] is the inertia matrix and is considered to be constant over any one particular orbit. Equation (5) then can be written as:

$$\vec{T}_E = [I]\dot{\vec{\omega}}_{VI} + \vec{\omega}_{VI} \times [I]\vec{\omega}_{VI} \tag{6}$$

The external torques, $\vec{T}_E$, are gravity gradient ($\vec{T}_{GG}$), solar radiation pressure ($\vec{T}_S$), and aerodynamic ($\vec{T}_A$). Equation (6) defined in the vehicle frame is given by:

$$\vec{T}_{GG} + \vec{T}_S + \vec{T}_A = [I]\dot{\vec{\omega}}^{\vee}_{VI} + \vec{\omega}^{\vee}_{VI} \times [I]\vec{\omega}^{\vee}_{VI} \tag{7}$$

The three frames of reference considered for this analysis are the inertial, rotating, and vehicle. The angular rates of the various reference frames are defined as follows:

$$\vec{\omega}_V = \vec{\omega}_I + \vec{\omega}_{VI} = \vec{\omega}_{VI}\text{ , since } \vec{\omega}_I = \vec{0} \tag{8}$$

$$\vec{\omega}_R = \vec{\omega}_I + \vec{\omega}_{RI} = \vec{\omega}_{RI} \tag{9}$$

$$\vec{\omega}_{VI} = \vec{\omega}_{VR} + \vec{\omega}_{RI} \tag{10}$$

Then, (11)

$$\vec{\omega}_{VI} = \vec{\omega}_{V} = \vec{\omega}_{VR} + \vec{\omega}_{RI}$$

Considering the spacecraft to be in a circular orbit and a z-local vertical mode, equation (9) becomes:

$$\vec{\omega}_{R} = \vec{\omega}_{RI} = (0, -\omega_0, 0)^T \tag{12}$$

where ω_o is the orbital rate.

Define the transformation matrix from the rotating to the vehicle frame as:

$$\left[T_{VR}\right] = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \tag{13}$$

which is an orthogonal transformation. Then equation (11) written in the vehicle frame is given by:

$$\vec{\omega}_{V}^{V} = \vec{\omega}_{VR}^{V} + \vec{\omega}_{R}^{V} = \vec{\omega}_{VR}^{V} + \left[T_{VR}\right]\vec{\omega}_{R} \tag{14}$$

Solving equation (14) for $\vec{\omega}_{VR}$V in component form yields:

$$\omega_{VRX}^{V} = \Delta\omega_X = \omega_{VX}^{V} + \omega_0 a_{12} \tag{15}$$

$$\omega_{VRY}^{V} = \Delta\omega_Y = \omega_{VY}^{V} + \omega_0 a_{22} \tag{16}$$

$$\omega_{VRZ}^{V} = \Delta\omega_Z = \omega_{VZ}^{V} + \omega_0 a_{32} \tag{17}$$

2.8.1.3. The Quaternion Solution of the Rotating Reference to Vehicle Reference Frame Coordinate Transformation.

The term $\vec{\omega}_{VR}V$ is the error rate generated due to the motion of the vehicle frame with respect to the rotating reference written in terms of the vehicle frame. The error rate will be used to generate the four parameters q_1, q_2, q_3, and q_4 from the equation

$$\dot{\vec{\rho}} = \frac{1}{2} \underline{\underline{\Omega}} \vec{\rho} \tag{18}$$

where
$$\vec{\rho} = (q_1, q_2, q_3, q_4)^T \tag{19}$$

and

$$\underline{\underline{\Omega}} = \begin{bmatrix} 0 & \Delta\omega_z & -\Delta\omega_y & \Delta\omega_x \\ -\Delta\omega_z & 0 & \Delta\omega_x & \Delta\omega_y \\ \Delta\omega_y & -\Delta\omega_x & 0 & \Delta\omega_z \\ -\Delta\omega_x & -\Delta\omega_y & -\Delta\omega_z & 0 \end{bmatrix} \tag{20}$$

which has symmplectic properties.

Then,

$$q_1 = \int \dot{q}_1 dt + q_1(0) \tag{21}$$

$$q_2 = \int \dot{q}_2 dt + q_2(0) \tag{22}$$

$$q_3 = \int \dot{q}_3 dt + q_3(0) \tag{23}$$

$$q_4 = \int \dot{q}_4 \, dt + q_4(0) \tag{24}$$

$$q_1(0) = q_2(0) = q_3(0) = 0 \text{ , and } q_4(0) = 1.0 \text{ .}$$

where

The quaternion Q is defined as: (25)

$$Q = q_4 + \vec{i}\, q_1 + \vec{j}\, q_2 + \vec{k}\, q_3$$

where q_1, q_2, q_3, and q_4 are real numbers and $\vec{i}$, $\vec{j}$, and $\vec{k}$ are hyper-imaginary numbers satisfying the conditions

$$\left.\begin{aligned} \vec{i}^{\,2} = \vec{j}^{\,2} = \vec{k}^{\,2} = -1 \\ \vec{i}\vec{j} = -\vec{j}\vec{i} = \vec{k} \\ \vec{j}\vec{k} = -\vec{k}\vec{j} = \vec{i} \\ \vec{k}\vec{i} = -\vec{i}\vec{k} = \vec{j} \end{aligned}\right\} \tag{26}$$

Equation (18) written out becomes

$$\dot{q}_1 = \frac{\frac{1}{2}\left[q_2 \Delta\omega_z - q_3 \Delta\omega_y + q_4 \Delta\omega_x\right]}{q} \tag{27}$$

$$\dot{q}_2 = \frac{\frac{1}{2}\left[-q_1 \Delta\omega_z + q_3 \Delta\omega_x + q_4 \Delta\omega_y\right]}{q} \tag{28}$$

$$\dot{q}_3 = \frac{\frac{1}{2}\left[q_1 \Delta\omega_y - q_2 \Delta\omega_x + q_4 \Delta\omega_z\right]}{q} \tag{29}$$

$$\dot{q}_4 = \frac{\frac{1}{2}\left[-q_1 \Delta\omega_x - q_2 \Delta\omega_y - q_4 \Delta\omega_z\right]}{q} \tag{30}$$

where division by the quantity,

$$q = \sqrt{Q^{*}Q} = \sqrt{q_1^2 + q_2^2 + q_3^2 + q_4^2}$$

which is the magnitude of the quaternion, guarantees orthogonality.

The advantage of the quaternion lies in its ability to define the rotational relationship between two coordinate systems using only four numbers as opposed to the nine elements of a direction cosine matrix. Listed in Table 2.8.1 are the coodinate transformation identities for the transformation matrix $[T_{VR}]$ for a yaw (Ψ), pitch (Θ), roll (Φ) sequence.

2.8.1.4 Generation of the Fuler Angles Using the Four Parameters

The Euler angles are determined from the following relationships:

$$\psi = \tan^{-1}\left(\frac{a_{12}}{a_{11}}\right) = \tan^{-1}\left[\frac{2(q_3q_4 + q_1q_2)}{q_1^2 - q_2^2 - q_3^2 + q_4^2}\right] \quad (31)$$

$$\theta = \sin^{-1}(-a_{13}) = \sin^{-1}\left[2(q_2q_4 - q_1q_3)\right] \quad (32)$$

$$\phi = \tan^{-1}\left(\frac{a_{23}}{a_{33}}\right) = \tan^{-1}\left[\frac{2(q_1q_4 + q_2q_3)}{-q_1^2 - q_2^2 + q_3^2 + q_4^2}\right] \quad (33)$$

It will be shown in the following section that the Fuler Angular Pates , θ,and Φ , can be easily determined using the Euler angles obtained from equations (31) through (33) and the angular rates detained from equations (15) through (17).

TABLE 2.8.1. - COORDINATE TRANSFORMATION IDENTITIES FOR YAW-PITCH-ROLL SEQUENCE.

DIRECTION COSINE	EULER ANGLES	FOUR PARAMETER
a_{11}	$\cos\theta\cos\psi$	$q_1^2-q_2^2-q_3^2+q_4^2$
a_{12}	$\cos\theta\sin\psi$	$2(q_3q_4+q_1q_2)$
a_{13}	$-\sin\theta$	$2(q_1q_3-q_2q_4)$
a_{21}	$\sin\phi\sin\theta\cos\psi-\cos\phi\sin\psi$	$2(q_1q_2-q_3q_4)$
a_{22}	$\sin\phi\sin\theta\sin\psi+\cos\phi\cos\psi$	$-q_1^2+q_2^2-q_3^2+q_4^2$
a_{23}	$\sin\phi\cos\theta$	$2(q_1q_4+q_2q_3)$
a_{31}	$\cos\phi\sin\theta\cos\psi+\sin\phi\sin\psi$	$2(q_2q_4+q_1q_3)$
a_{32}	$\cos\phi\sin\theta\sin\psi-\sin\phi\cos\psi$	$2(q_2q_3-q_1q_4)$
a_{33}	$\cos\phi\cos\theta$	$-q_1^2-q_2^2+q_3^2+q_4^2$

2.8.1.4.1 <u>Generation of the Euler Angular Rates</u>-Define the following orthogonal transformation matrices:

$$[T(\psi)] = \begin{bmatrix} c\psi & s\psi & 0 \\ -s\psi & c\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad (34)$$

$$[T(\theta)] = \begin{bmatrix} c\theta & 0 & -s\theta \\ 0 & 1 & 0 \\ s\theta & 0 & c\theta \end{bmatrix} \qquad (35)$$

$$[T(\phi)] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c\phi & s\phi \\ 0 & -s\phi & c\phi \end{bmatrix} \qquad (36)$$

where

$s\psi = \sin\psi$, $c\psi = \cos\psi$, etc.

Using the transformation matrices defined by equations (34) through (36), the vehicle rate $\vec{\omega}_V^V$, in terms of $\vec{\omega}_R$ and the Euler Angular Rates is given by:

$$\vec{\omega}_V^V = [T(\phi)][T(\theta)][T(\psi)]\,\vec{\omega}_R + [T(\phi)][T(\theta)](0,0,\dot{\psi})^T + [T(\phi)](0,\dot{\theta},0)^T + (\dot{\phi},0,0)^T \tag{37}$$

where $$[T_{VR}] = [T(\phi)][T(\theta)][T(\psi)] \tag{38}$$

From equation (14)

$$\vec{\omega}_{VR}^V = \vec{\omega}_V^V - [T_{VR}]\,\vec{\omega}_R \triangleq \Delta\vec{\omega} \tag{39}$$

Using equation (39), equation (37) can now be written as:

$$\Delta\vec{\omega} = [T(\phi)][T(\theta)](0,0,\dot{\psi})^T + [T(\phi)](0,\dot{\theta},0)^T + (\dot{\phi},0,0)^T \tag{40}$$

Equation (40) in component from becomes:

$$\Delta\omega_X = \dot{\phi} - \dot{\psi}\, s\theta \tag{41}$$

$$\Delta\omega_Y = \dot{\theta}\, c\phi + \dot{\psi}\, c\theta s\phi \tag{42}$$

$$\Delta\omega_Z = -\dot{\theta}\, s\phi + \dot{\psi}\, c\theta c\phi \tag{43}$$

Solving for the Fuler Angular Pates and expressing the results in matrix form yields,

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} 1 & \sin\phi\tan\theta & \cos\phi\tan\theta \\ 0 & \cos\phi & -\sin\phi \\ 0 & \dfrac{\sin\phi}{\cos\theta} & \dfrac{\cos\phi}{\cos\theta} \end{bmatrix} \begin{bmatrix} \Delta\omega_x \\ \Delta\omega_y \\ \Delta\omega_z \end{bmatrix} \tag{44}$$

It should be noted that the matrix defined in equation (44) is not an orthogonal matrix, and that four of its elements are undefined for θ = 90 deg.

The generation of the external torques applied in the vehicle reference frame requires the use of the transformation matrix $[T_{VR}]$ and its inverse $[T_{VR}]^{-1}$. Shown in Figure 2.8.1 is a block diagram of the uncontrolled rigid dynamic model.

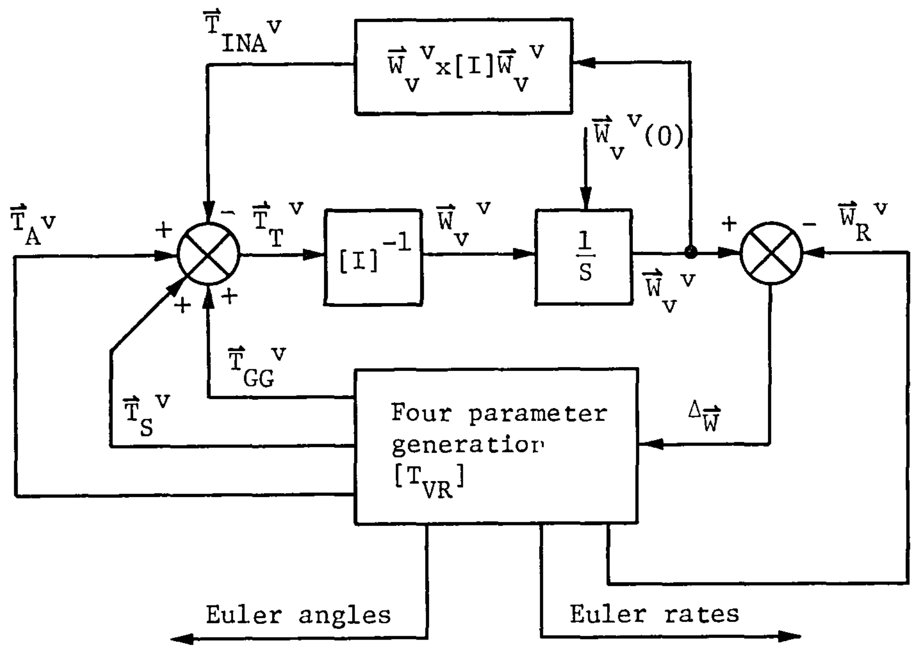


Figure 2.8.1. - Block diagram of rigid body dynamic model.

2.8.1.5 Torque Due To Gravity Gradient

The torque generated due to gravity gradient and subjected to a vehicle in a z-local mode produces a restoring torque that has a stabilizing effect. The z-local mode is shown in Figure 2.8.2.

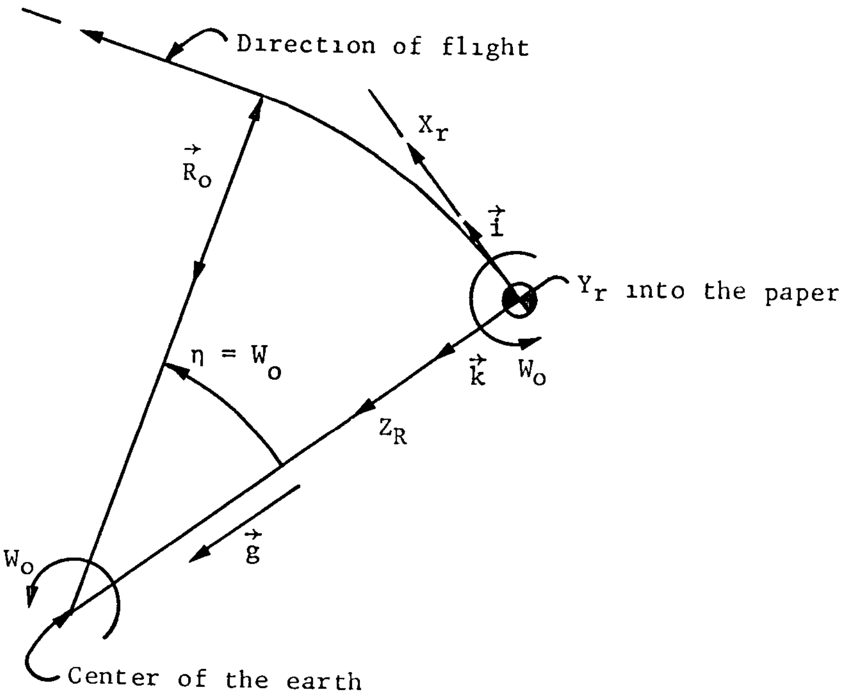


Figure 2.8.2. - Z-local mode.

The torque generated due to gravity gradient is defined by:

$$\vec{T}_{GG} = 3\omega_o^2 \begin{bmatrix} 0 & -\gamma & \beta \\ \gamma & 0 & -\alpha \\ -\beta & \alpha & 0 \end{bmatrix} \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{xy} & I_{yy} & -I_{yz} \\ -I_{xz} & -I_{yz} & I_{zz} \end{bmatrix} \begin{bmatrix} \alpha \\ \beta \\ \gamma \end{bmatrix} \tag{45}$$

where α, β and γ are the direction cosines. The direction cosines of the X_R, Y_P, and Z_P axis system relative to the direction of g are defined by:

$$\begin{bmatrix} \alpha \\ \beta \\ \gamma \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \tag{46}$$

where $$\vec{g} = g(\alpha\vec{i} + \beta\vec{j} + \gamma\vec{k}) = g\vec{k} \tag{47}$$

Then the gravity gradient torque with the R reference frame is given by:

$$\vec{T}_{GG}^{R} = 3\omega_o^2 (I_{yz}\vec{i} - I_{xz}\vec{j} + 0\vec{k}) \tag{48}$$

For the assumption that the vehicle and reference frame coincide, equation (48) implies that constant gravity gradient torques will exist about the x_R and y_R axes, which will in effect cause a residual momentum to exist at the

end of each orbit with respect to the inertial reference frame. Considering the case where only principal axes of inertia exist for the vehicle, then equation (48) would be:

$$\vec{T}_{GG}^{R} = \vec{O} \tag{49}$$

Gravity torques will be produced as a result of the vehicle and rotating reference frame not coinciding. The direction cosines for this case are defined by:

$$\begin{bmatrix} \alpha \\ \beta \\ \gamma \end{bmatrix} = \left[T_{VR}\right](0, 0, 1)^{T} = \begin{bmatrix} a_{13} \\ a_{23} \\ a_{33} \end{bmatrix} \tag{50}$$

Substituting the direction cosines from equation (50) into equation (45) yields:

$$\vec{T}_{GG}^{v} = 3\omega_o^2 \begin{bmatrix} \Delta I_x \gamma\beta \\ \Delta I_y \alpha\gamma \\ \Delta I_z \alpha\beta \end{bmatrix}$$

$$\vec{T}_{GG}^{v} = 3\omega_o^2 \begin{bmatrix} \Delta I_x a_{23} a_{33} \\ \Delta I_y a_{13} a_{33} \\ \Delta I_z a_{13} a_{23} \end{bmatrix} \tag{51}$$

where:

$$\left.\begin{aligned} \Delta I_x &= I_{zz} - I_{yy} \\ \Delta I_y &= I_{xx} - I_{zz} \\ \Delta I_z &= I_{yy} - I_{xx} \end{aligned}\right\} \tag{52}$$

The gravity gradient torque with respect to the vehicle frame and including the cross products of inertia is defined by:

$$\vec{T}_{GG}^{v} = 3\omega_o^2 \begin{bmatrix} 0 & -a_{33} & a_{23} \\ a_{33} & 0 & -a_{13} \\ -a_{23} & a_{13} & 0 \end{bmatrix} \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{xy} & I_{yy} & -I_{yz} \\ -I_{xz} & -I_{yz} & I_{zz} \end{bmatrix} \begin{bmatrix} a_{13} \\ a_{23} \\ a_{33} \end{bmatrix} \tag{53}$$

In the following analysis the only external torque considered to act on the rigid body is gravity gradient. Considering only principal axes of inertia and no out-of-plane motion about the x_v or z_v axis and using the direction cosines defined as a function of the Euler angles, the gravity torques as defined by equation (51) become:

$$\vec{T}_{GG}^{v} = \begin{bmatrix} 0 \\ -\frac{3\omega_o^2}{2}(I_{xx} - I_{zz})\sin 2\theta \\ 0 \end{bmatrix} \tag{54}$$

Then considering $\vec{\omega}_{VI}V$ to be small, equation (7) becomes:

$$\vec{T}_{GG}^{v} = [I]\,\dot{\vec{\omega}}_{VI}^{v} \tag{55}$$

Equation (55) in component form and for small angle approximation becomes:

$$I_{xx}\ddot{\phi} = 0 \tag{56}$$

$$I_{yy}\ddot{\theta} = -3\omega_0^2 (I_{xx} - I_{zz})\theta \tag{57}$$

$$I_{zz}\ddot{\psi} = 0 \tag{58}$$

The solution of equation (57) for $I_{xx} > I_{zz}$ yields.

$$\theta(t) = \frac{\dot{\theta}(0)}{B}\sin Bt + \theta(0)\cos Bt \tag{59}$$

where:

$$B = \sqrt{\frac{3\omega_0^2 (I_{xx} - I_{zz})}{I_{yy}}} \quad \text{rad/sec}$$

and $\dot{\theta}(0) = -\omega_0$ the orbital rate (rad/s), $\theta(0) = 0$. The vehicle will execute simple harmonic motion about the local vertical. For the case where $I_{zz} > I_{xx}$, the solution of equation (57) yields:

$$\theta(t) = \frac{\dot{\theta}(0)}{B}\sinh Bt + \theta(0)\cosh Bt \tag{60}$$

where (61)

$$B = \sqrt{\frac{3\omega_o^2 (I_{zz} - I_{xx})}{I_{yy}}} \text{ rad/sec}$$

Shown in Figure 2.8.3 is a time response plot of equation (56) indicating that the solution is an unbounded function of time for $t > o$.

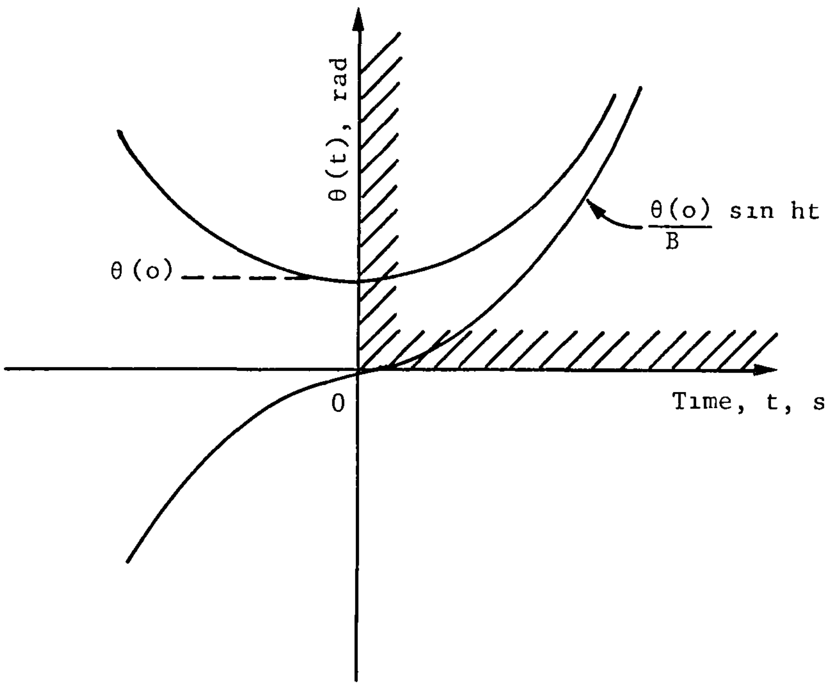


Figure 2.8.3. - Plot of θ(t) as a function of time using equation (56).

The result as shown in Figure 2.8.3 is due to the fact that the minimum axis of inertia is not along the z-local vertical axis as is the case for $I_{xx} > I_{zz}$.

2.8.1.6 Aerodynamic Forces and Torques

The gravity gradient torques discussed in the preceding section are well defined due to the fact that the mass moments of inertia of the vehicle and the orbital are, to a degree, easy to determine. On the other hand, aerodynamic forces and torques are a function of a number of parameters, which in some cases need complex mathematical models and/or testing to determine the numerical value of required parameters. Shown in Figure 2.8.4 is the ASSA spacecraft with its physical dimensions, geometric shapes, and projected areas that were used in the following development of aerodynamic force and torque mathematic models implemented into the PCD module. Figure 2.8.5 illustrates the aerodynamic body axes system related to the vehicle velocity vector.

This spacecraft is modeled through definition of areas A_{11}, A_{12}, and areas representing the feed masts. At present this spacecraft configuration is hard-coded into the module. Analysis of other configurations will require some relatively minor modifications.

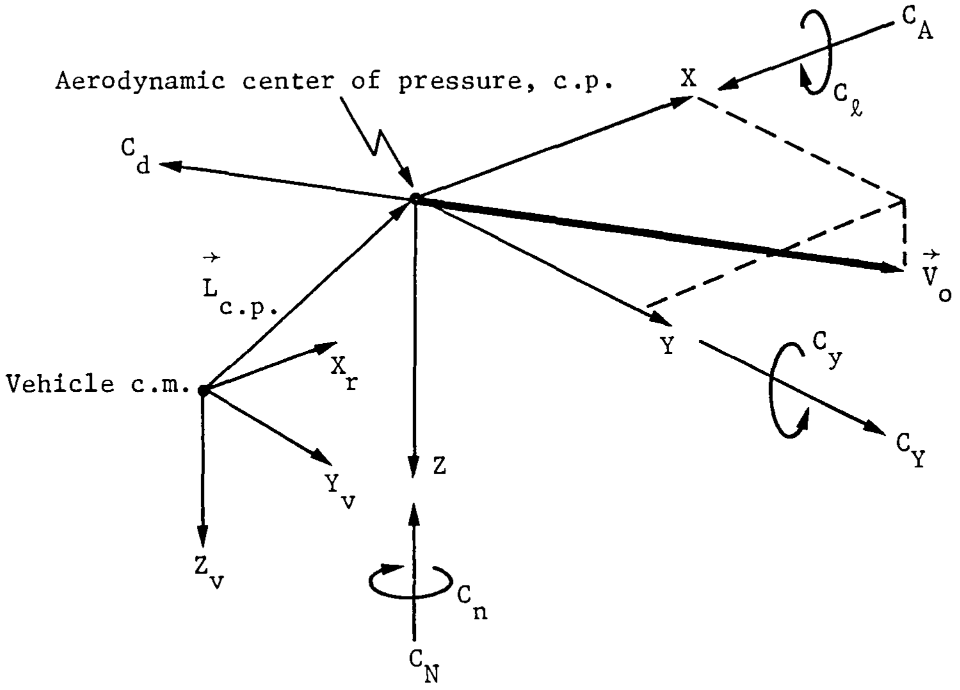
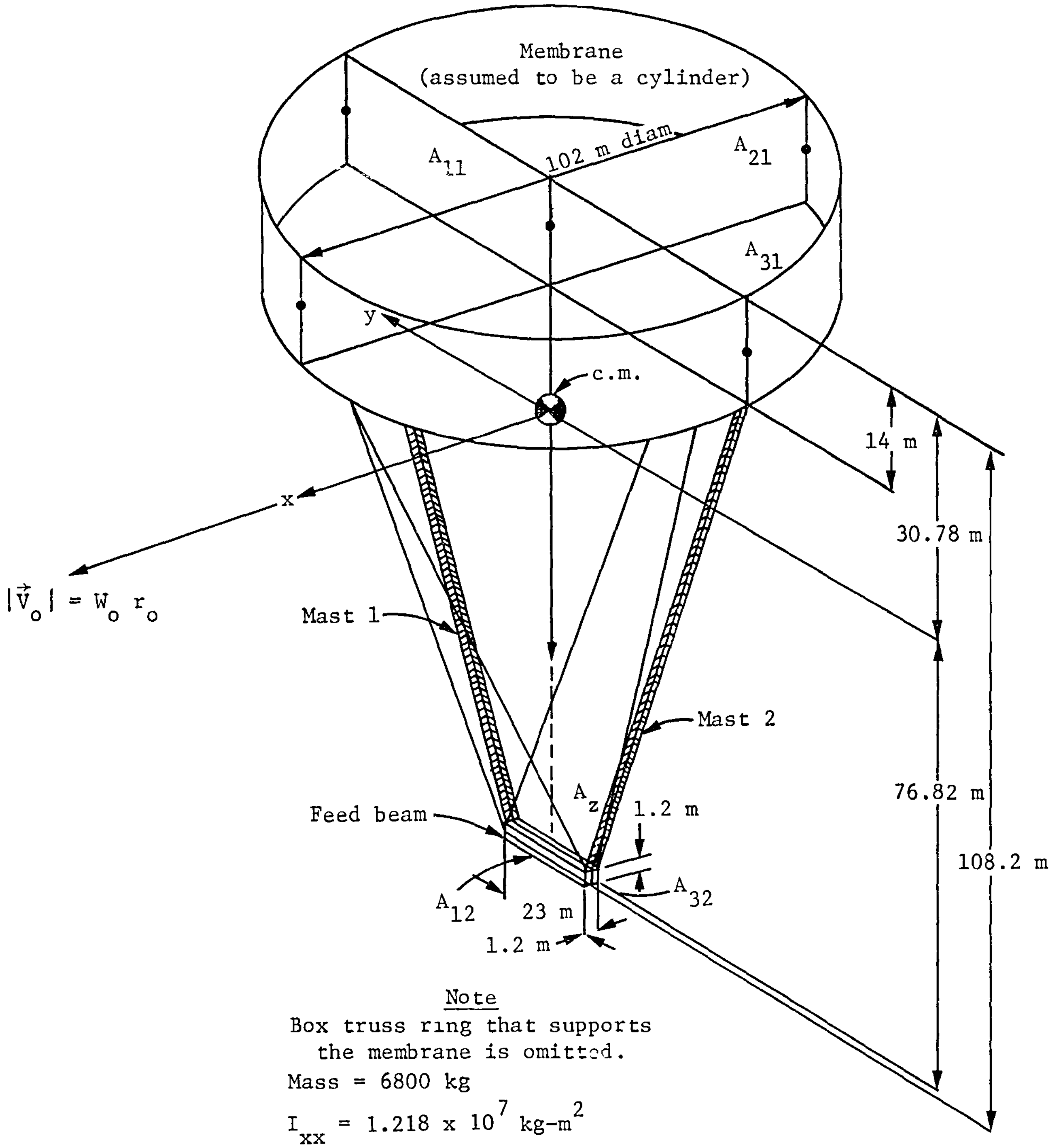


Figure 2.8.5. - Aerodynamic body axis system related to the vehicle velocity vector.



Note

Box truss ring that supports the membrane is omitted.

Mass = 6800 kg

$I_{xx} = 1.218 \times 10^7$ kg-m^2

$I_{yy} = 1.218 \times 10^7$ kg-m^2

$I_{zz} = 0.959 \times 10^7$ kg-m^2

Cross products of inertia are zero.

Figure 2.8.4. - ECMM spacecraft physical dimensions and properties.

Aerodynamic coefficients and symbols as presented in Figure 2.8.5 are defined as follows:

A_{ref}	Reference area
C_A	Axial force coefficient, $\frac{F_A}{q\ A_{ref}}$
C_l	Rolling moment coefficient, $\frac{M_X}{q\ A_{ref}\ D_{ref}}$
Cm	Pitching moment coefficient, $\frac{M_Y}{q\ A_{ref}\ D_{ref}}$
C_N	Normal force coefficient, $\frac{F_N}{q\ A_{ref}}$
C_n	Yawing moment coefficient, $\frac{M_Z}{q\ A_{ref}\ D_{ref}}$
C_Y	Side force coefficient, $\frac{F_Y}{q\ A_{ref}}$
D_{ref}	Reference diameter
F_A	Axial force (positive in the negative direction of X)
F_N	Normal force (positive in the negative direction of Z)
F_Y	Side force (positive in the positive direction of Y)
M_X	Rolling moment, i.e , moment about the X-axis (a positive rolling moment tends to rotate the positive Y-axis toward the positive Z axis)
M_Y	Pitching moment, i e , moment about the Y-axis (a positive pitching moment tends to rotate the positive Z-axis toward the positive X-axis)
M_Z	Yawing moment, i e , moment about the Z-axis (a positive yawing moment tends to rotate the positive X-axis toward the positive Y-axis)
q	Dynamic pressure, $\frac{1}{2} \rho v^2$
V_X, V_Y, V_Z	Components of the velocity in the direction of the respective X, Y, Z axis (positive in the positive direction of the coordinate denoted by the subscript)
X, Y, Z	Longitudinal, lateral, and normal axes, respectively
$\vec{V}_o$	Velocity of the body relative the the surrounding atmosphere
V_o	Speed of the body relative to the surrounding atmosphere, $V_o = \lvert \vec{V}_o \rvert$
ρ	Atmospheric density

Moment coefficients can be transfered to an aerodynamic body axis system with its origin located at the vehicle center of mass by using the following equations.

$$C_{cm} = C_m + C_A \frac{z_{cp}}{D_{REF}} - C_N \frac{x_{cp}}{D_{REF}} \tag{64}$$

$$C_{n_{cm}} = C_n - C_Y \frac{x_{cp}}{D_{REF}} - C_A \frac{y_{cp}}{D_{REF}}$$

$$C_{l_{cm}} = C_l + C_Y \frac{z_{cp}}{D_{REF}} - C_N \frac{y_{cp}}{D_{REF}}$$

Aerodynamic moments about axes passing through the center of mass can then be calculated with the following equations:

$$T_{A_x} = q\, A_{REF}\, D_{REF}\, C_{l_{cm}} \tag{65}$$

$$T_{A_y} = q\, A_{REF}\, D_{REF}\, C_{m_{cm}} \tag{66}$$

$$T_{A_z} = q\, A_{REF}\, D_{REF}\, C_{n_{cm}} \tag{67}$$

The free molecular flow approach is indispensable in problems where aerodynamic forces, even though negligible with respect to the gravitational forces, are applied over long periods of time and, consequently, produce important effects on the nature of the resulting trajectories. A flow satisfying the condition $M/R_e \gg 1$, must be treated with the kinetic theory of gases. For this flow, the incident molecules are undisturbed by the presence of the spacecraft, and the reemitted molecules collide with the free-stream molecules only at a great distance from the body; hence, the aerodynamic forces are essentially governed by the interaction of the impinging molecules and the

surface. In the case of free molecular flow the aerodynamic moment coefficient are equal to zero. Then, equations (65) through (67) can be written as:

$$T_{AX}^{V} = q A_{REF} (C_A z_{cp} - C_N x_{cp}) \tag{68}$$

$$T_{AY}^{V} = q A_{REF} (-C_Y x_{cp} - C_A y_{cp}) \tag{69}$$

$$T_{AZ}^{V} = q A_{REF} (C_Y z_{cp} - C_N y_{cp}) \tag{70}$$

The velocity of the vehicle relative to the surrounding atmosphere is defined in the rotating reference frame as:

$$\vec{V}_o^R = \omega_o R_o \vec{i} + 0\vec{j} + 0\vec{k} \tag{71}$$

The drag coefficient, C_D, in the rotating reference frame for the vehicle and reference axes misaligned is given by:

$$C_D^R = C_A a_{11} + C_Y a_{21} + C_N a_{31} \tag{72}$$

The force due to aerodynamic drag is then given by:

$$\vec{F}_D^R = C_D^R q A_{REF} \vec{i} \tag{73}$$

in the reference frame and in the vehicle frame is given by:

$$F_{D_x}^{v} = C_D^R q A_{REF} a_{11} \tag{74}$$

$$F_{D_y}^{v} = C_D^R q A_{REF} a_{21} \tag{75}$$

$$F_{D_z}^{v} = C_D^R q A_{REF} a_{31} \tag{76}$$

Equations (74) through (76) are now defined in terms of a general equation. Define the following equation;

$$(F_{Akj}^{3}) = A_{jk} C_{Djk} q \left|(U_A^3)_j\right| (U_A^3)_l \tag{77}$$

where 3 defines the vehicle reference frame;

j = 1, 2, 3 vehicle fixed axes;

l = 1, 2, 3 component of aerodynamic force of the jth area;

k = 1, 2 designates the areas above and below the c.m. of the vehicle;

and

$$\begin{aligned} UA3(1) &= -a_{11} \\ UA3(2) &= -a_{21} \\ UA3(3) &= -a_{31} \end{aligned} \tag{78}$$

define the direction cosines.
The components of the aerodynamic forces in the vehicle frame are given by;

$$(F_A^3)_\ell = \sum_{k=1}^{2} \sum_{j=1}^{3} (F_{Akj}^3)_\ell \quad , \quad \ell = 1,2,3 \tag{79}$$

which is the general expression for equations (74) through (76). The torque due to aerodynamic forces in a generalized form is given by;

$$(T_{Akj}^3) = (L_{cpjk\ell}^3)(F_{Akj}^3)_\ell \tag{80}$$

where L_{cpjlk}^3 is the ℓ component of CM to center of pressure (CP) with components given in the vehicle frame. The components of the aerodynamic torques in the vehicle frame, which are a generalized form of equations (68) through (70) are defined by:

$$(T_A^3)_\ell = \sum_{k=1}^{2} \sum_{j=1}^{3} (T_A^3)_\ell \tag{81}$$

Table 2.8.2 is a summary of the data considered to be representative of the aerodynamic parameters of the spacecraft shown in Figure 2.8.4. Again, it must be noted that the existing code incorporates these data within the module. Thus, use of the module for other spacecraft will require internal changes to projected areas, drag coefficiants, and c.p. lever arm. The associated variables and arrays are defined and described through commentation internal to the code.

TABLE 2.8.2. - AERODYNAMIC MODEL DATA PARAMETERS.

Geometric shape	Projected areas (A_{jk}) m^2		Drag coefficient, CD_{jk}		Distance from c.m.to c.p. of respective projected areas, (L^3_{cpjkl}), m		
					x	y	z
Cylinder	A11	1442	CD11	2.5	0	0	-23.78
Cylinder	A21	1442	CD21	2.5	0	0	-23.78
Flat Circular Disk	A31	7850	CD31	4.0	0	0	-23.78
Flat Plate	A12	28	CD12	4.0	0	0	76.82
Flat Plate	A22	28	CD22	4.0	0	0	76.82
Flat Plate	A32	1.44	CD32	4.0	0	0	76.82

2.8.1.7 Atmospheric Mass Density Model

The atmospheric mass density model used is the 1976 U.S. Standard Atmosphere. The average mass density, ρ , is plotted as a function of orbital altitude, h, as shown in Figure 2.8.6. The data for the previously used atmosphere model terminated at an orbital altitude of 700 km, whereas the 1976 data are available up to and including a 1000-km altitude. Figure 2.8.7 illustrates the variation of the dynamic pressure with altitude for circular orbits using the 1976 average atmospheric data. The mathematical model used to generate the dynamic pressure for a circular orbit at a specified altitude is defined by:

$$q = \frac{1}{2} \rho V^2 \qquad (82)$$

In the module the value of ρ is obtained by performing a linear interpolation on the exponents as a function of altitude. The exponent (α) is then used to calculate ρ from:

$$\rho = 10^{\alpha} \qquad (83)$$

Plotted in Figure 2.8.8 are the exponents vs. altitude.

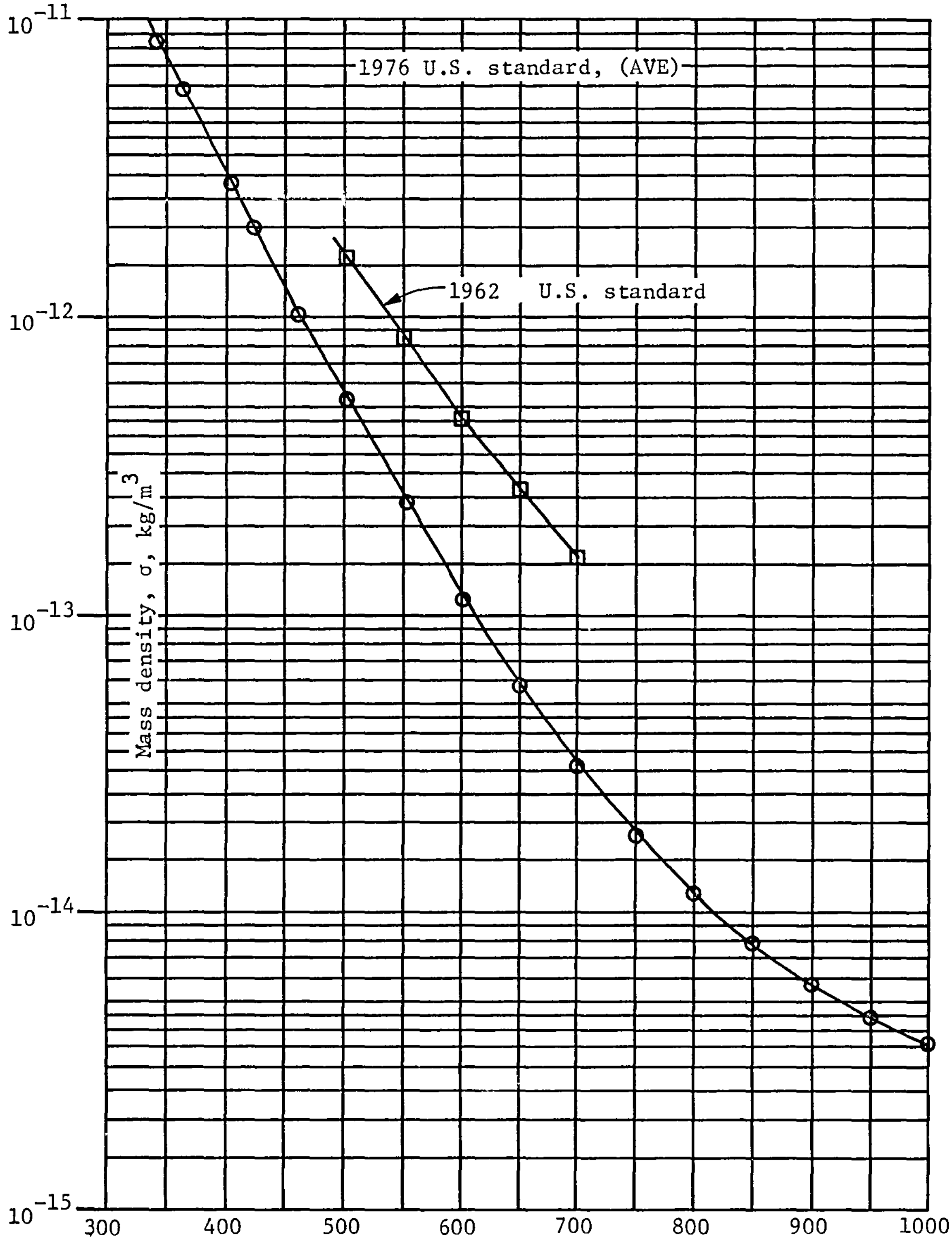


Figure 2.8.6. - 1976 U.S. standard atmosphere, average.

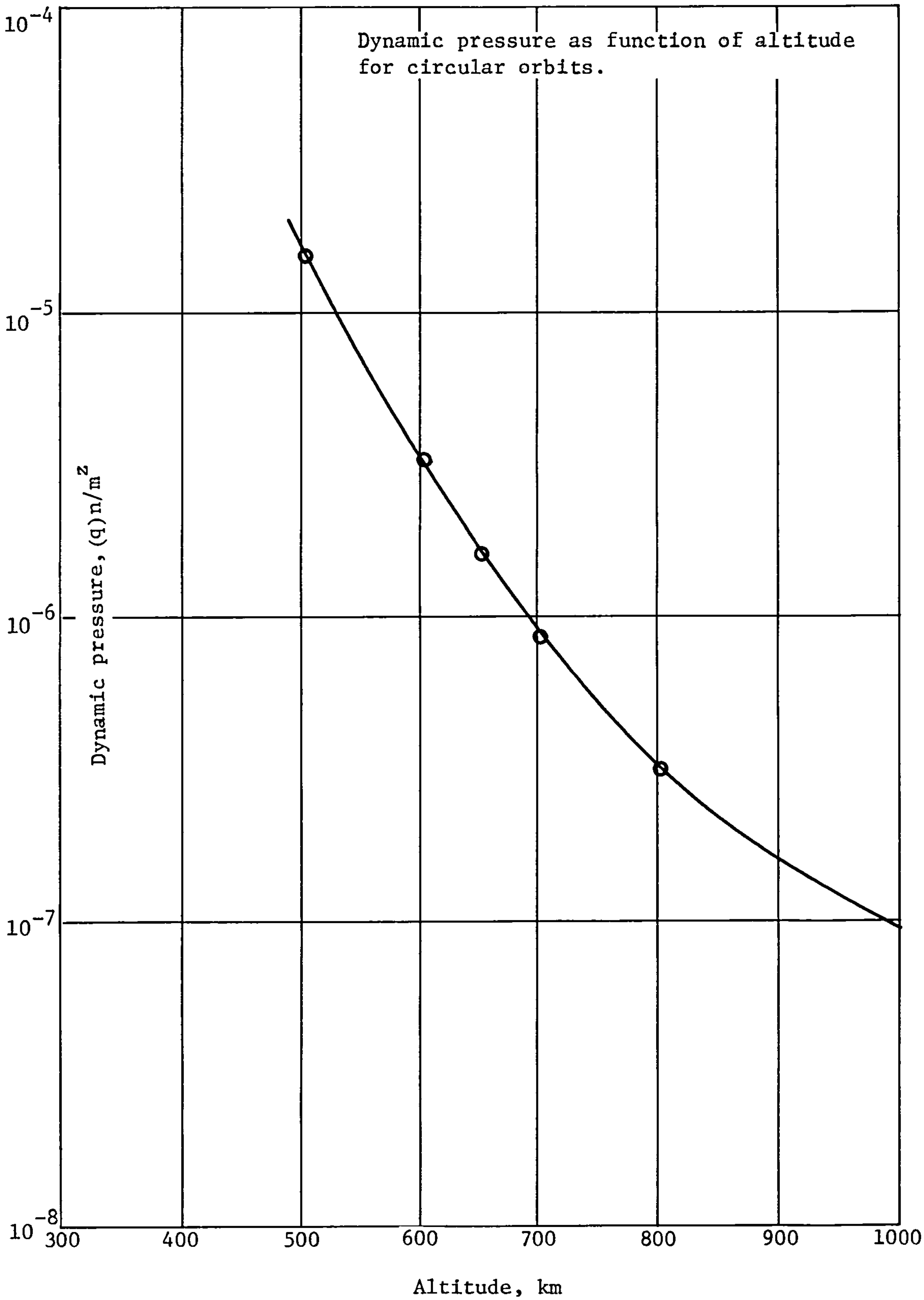


Figure 2.8.7. - Dynamic pressure versus altitude.

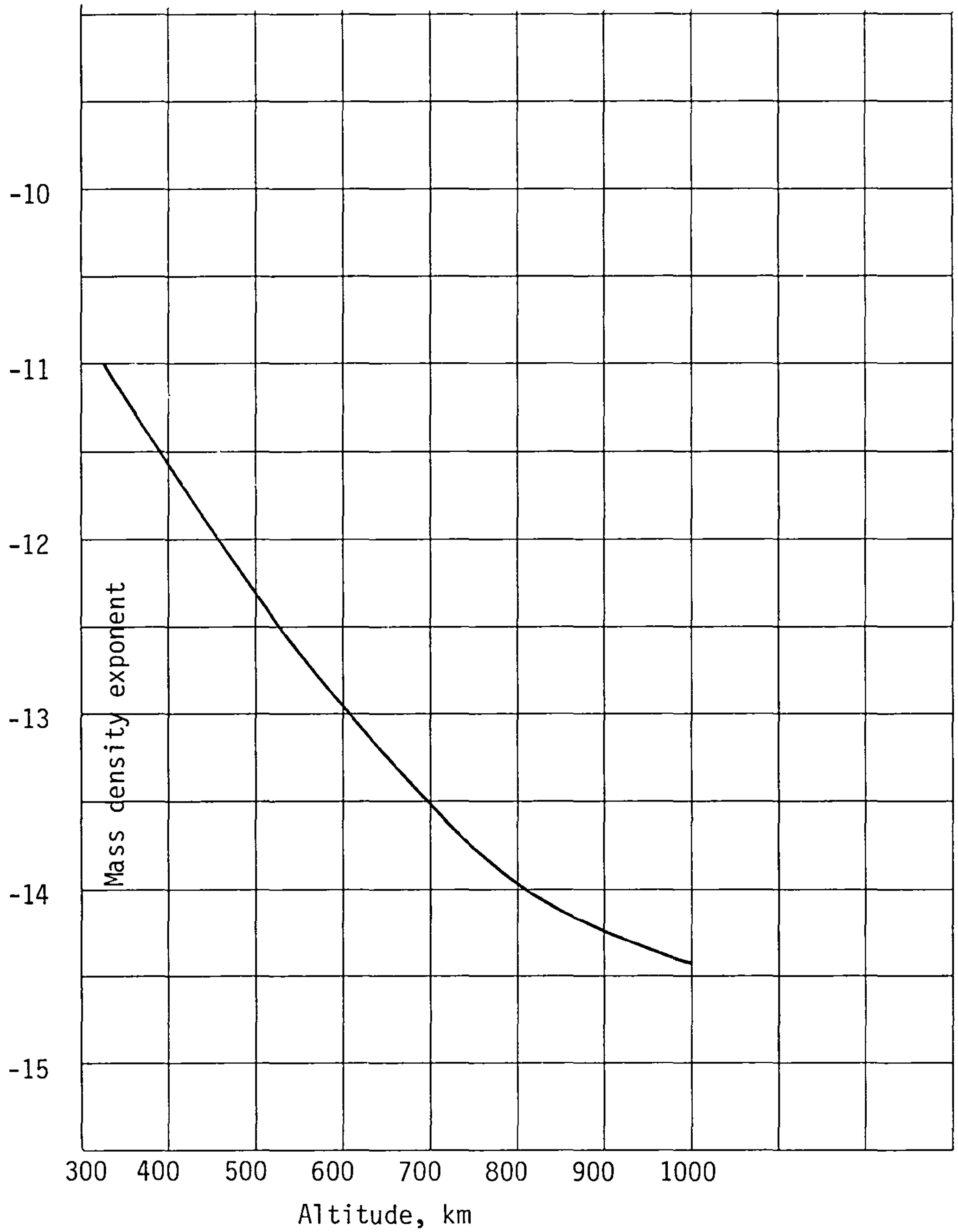


Figure 2.8.8.-Mass density exponents vs. altitude.

2.8.1.8 Torque Due to Solar Pressure

The torque on a space vehicle due to solar radiation pressure is defined by (reference 3, 4):

$$T_S = P_S L_S A_S \cos E \qquad \text{(absorbent body)} \tag{84}$$

$$T_S = 2P_S L_S A_S \cos^2 E \quad \text{(reflective body)} \tag{85}$$

where:

T_S = torque due to solar radiation, N-m;

P_S = radiation pressure, 4.6206×10^{-6} N/m^2 for Earth-orbiting spacecraft;

L_S = distance between vehicle center of mass and center of radiation pressure, m;

A_S = projected area of the vehicle normal to the Sun, m^2;

F = the angle the incoming radiation makes with the direction normal to the suface area, deg.

The model developed to determine the solar forces and torques assumed the membrane antenna to be a reflective body and E equal to zero degrees. Also included in the model was the sun line as a function of the angle Beta (β), which is defined as the angle between the sun line and orbit plane.

Figure 2.8.9 illustrates the spacecraft in a circular orbit for Beta equal to zero degrees. The angle x, which is used to determine the occulted region of the orbit, is defined by:

$$\begin{aligned} x &= \cos^{-1}\left(\frac{R_0 - h}{R_0}\right) \\ &= \cos^{-1}\left(1 - \frac{h}{R_0}\right) \end{aligned} \tag{86}$$

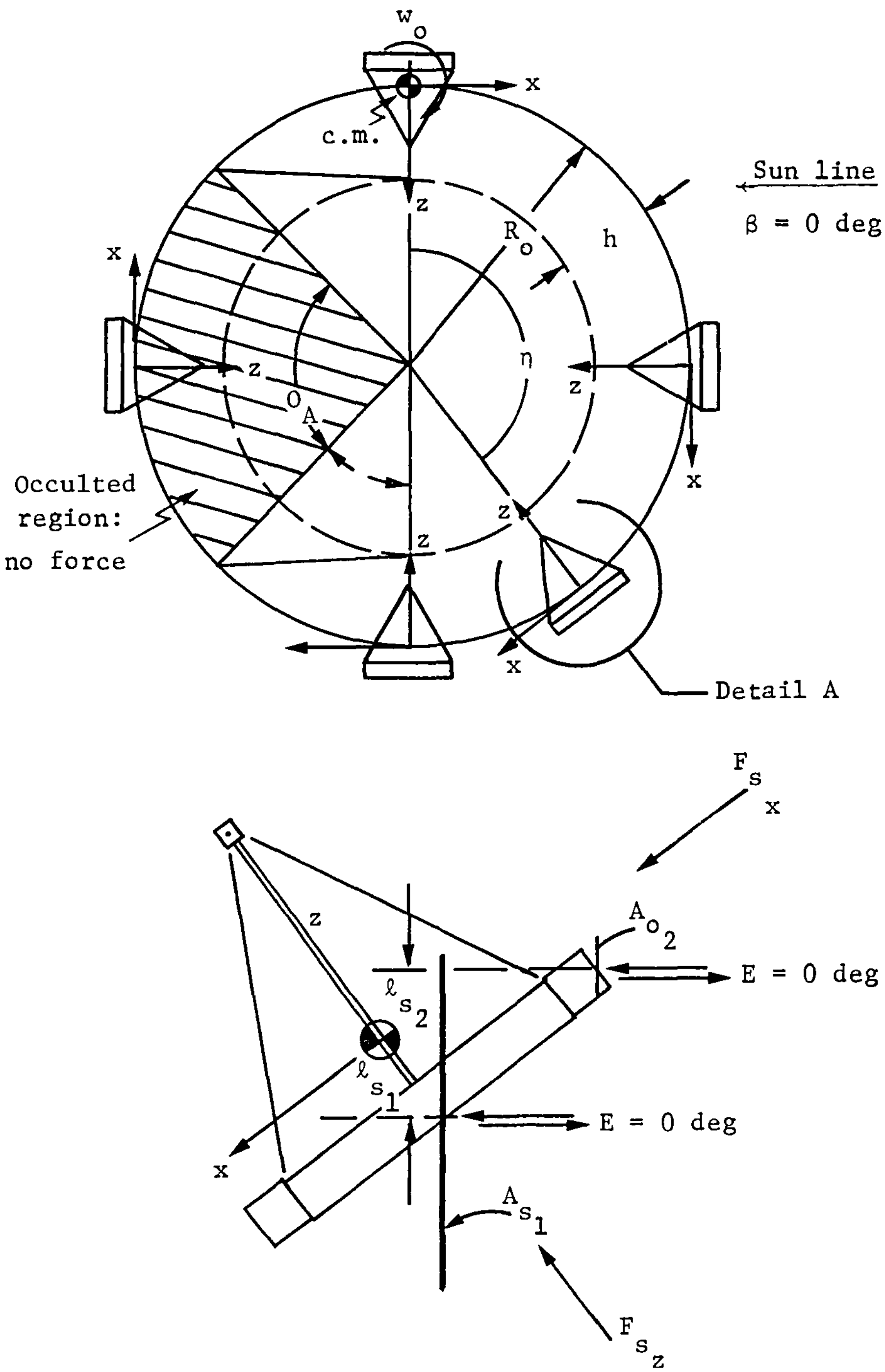
The angle defining the occulted region is then given by:

$$\theta_A = 180^\circ - 2\cos^{-1}\left(1 - \frac{h}{R_0}\right) \qquad (87)$$

The implication of equation (87) is that the greater the orbit altitude, h, the smaller the occulted region. There will exist times during the mission, in the case of large orbit inclination angles, for which no occulted region exists. This case is illustrated in Figure 2.8.10. The inclination angle, as a function of orbit altitude, which will produce an occulted region is defined by:

$$i < 67^\circ - \cos^{-1}\left(1 - \frac{h}{R_0}\right) \qquad (88)$$

Shown in Figure 2.8.11 is a plot of orbit inclination as a function of orbit altitude. Orbits with no occulted region are subjected to continuous solar radiation pressure force and torque over a long period. This presents difficult problems in a momentum management scheme if momentum exchange devices are considered for use in trying to compensate the torque due to solar radiation pressure.



Detail A

Figure 2.8.9. - Spacecraft orbit for β = 0 deg.

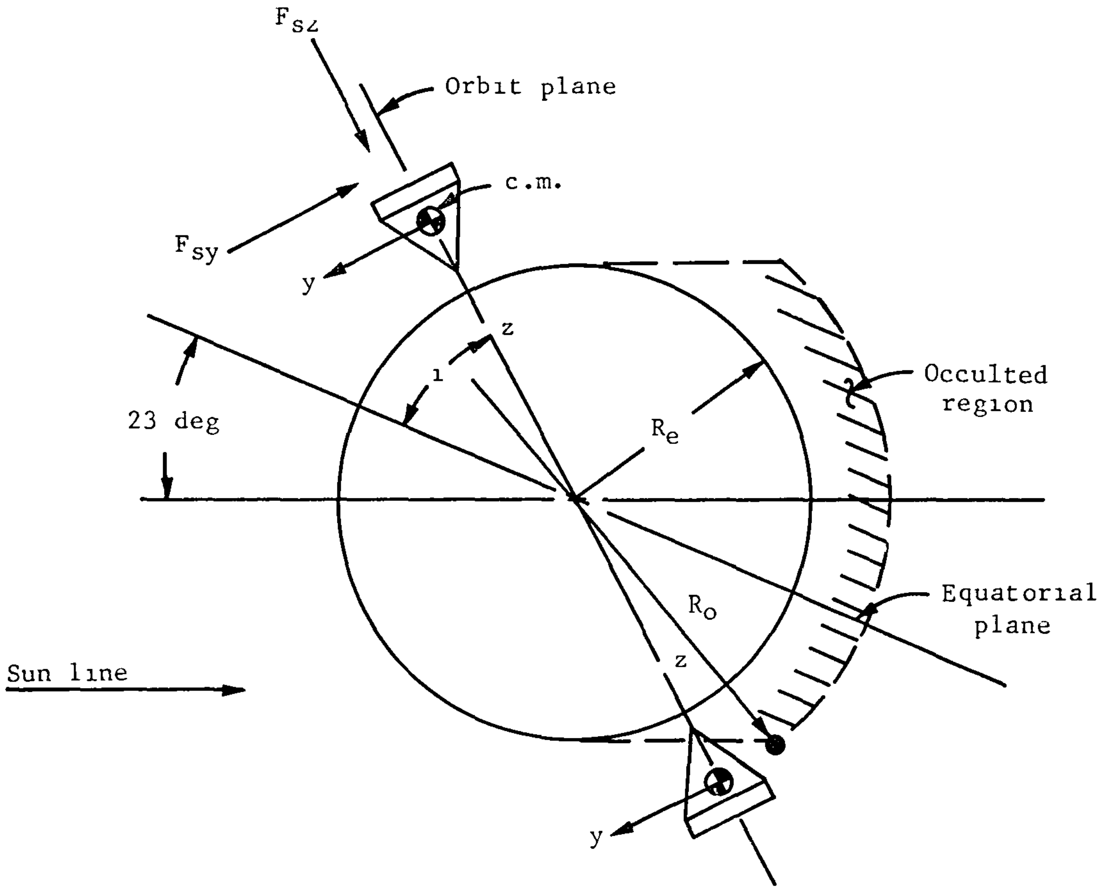


Figure 2.8.10. - Spacecraft orbit for inclination angle and β ≠ 0 deg.

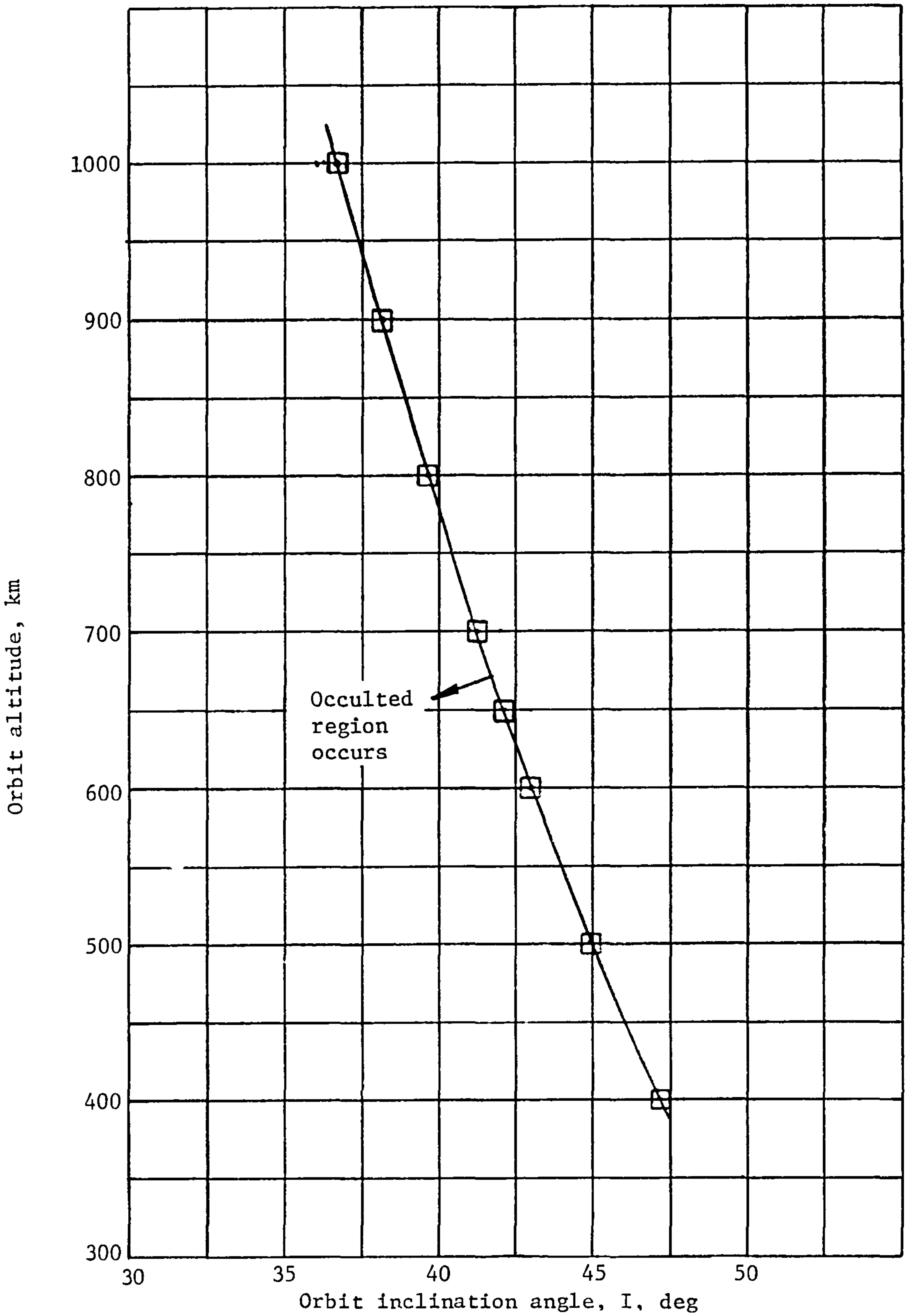


Figure 2.8.11 - Orbit inclination vs orbit altitude.

2.8.2 RCD Module User Instructions

The user session described in this section shows the user prompts and responses for execution of the module in the stand-alone modified mode. This latter mode is referred to as a stand-alone mode because it does not require prior execution of a model generator. The first input requested of the user is the definition of RCD module execution mode.

```
ENTER A 1 IF THE TTSS MODE IS TO BE USED
      OR A 0 IF THE STANDALONE MODE IS TO BE USED

? 0
```

If the TTSS mode is selected the input sequence described in reference 4 will be followed. If the standalone mode is selected the following sequence will commence. On entering the RCD program the user is asked to enter the name of the input data base file.

```
ENTER NAME OF INPUT DATA BASE FILE
   0 - DEFAULT FILE (LASSDB)
  PFN   PERMANENT FILE NAME
? RCDTEST
```

For either mode the following input information will be displayed and the user given the option to modify items as desired:

```
RIGID-BODY CONTROL DYNAMICS (RCD) INPUT

    1 00000E+06      1   H      - ORBIT ALTITUDE (METERS)
      50000          2   INCLIN - ORBIT INCLINATION (RADIANS)
      50000          3   PSIN   - ORBIT ASCENDING NODE (RADIANS)
     3 0000          4   TFUEL  - TIME BETWEEN REFUELING (YEARS)
     2000 0          5   ISP    - SPECIFIC IMPULSE (NEWTON-SECONDS PER KILOGRAM)
    0                6   CD     - AERODYNAMIC DRAG COEFFICIENT
     2 0000          7   IE     - ORIENTATION FLAG (= 1  FOR INERTIAL OR = 2  FOR
EARTH)
     1 5700          8   OPSI   - EULER ANGLES (3) DEFINING ORIENTATION OF SPACECR
AFT FOR BOTH
     0               9   OTHETA    INERTIAL AND EARTH   OPSI IS ROTATION ABOUT TH
E Z AXIS,
     0              10   OPHI      OTHETA ABOUT THE NEW Y AXIS, OPHI ABOUT X   (R
ADIANS)
    1 00000E-04     11   WM3(1) - SPACECRAFT MANEUVER RATE REQUIREMENT X, Y, Z COM
PONENTS
    1 00000E-04     12   WM3(2)    RESPECTIVELY (RADIANS PER SECOND)
    1 00000E-04     13   WM3(3)
    1 00000E-06     14   ALFAM3 - SPACECRAFT MANEUVER ACCELERATION REQUIREMENT X,
```

```
Y, Z
    1 00000E-06    15     (2)     COMPONENTS RESPECTIVELY (RADIANS PER SECOND SQ
UARED)
    1 00000E-06    16     (3)
      20000        17   NM      - NUMBER OF MANEUVERS PER ORBIT
    1 74000E-04    18   E3(1)   - INERTIAL ATTITUDE ACCURACY REQUIREMENT X, Y, Z C
OMPONENTS
    1 74000E-04    19   E3(2)     RESPECTIVELY (RADIANS)
    1 74000E-04    20   E3(3)
    0              21   UAS3(1)- UNIT VECTOR ALONG AMCD SPIN AXIS X, Y, Z COMPONE
NTS
    0              22   UAS3(2)   RESPECTIVELY
     1 0000        23   UAS3(3)
    1 00000E-02    24   GAMMA   - AMCD PIVOT AXIS ANGULAR RANGE (RADIANS)
     129 39        25   RO      - AMCD UNIT WHEEL RADIUS (METERS)
     1 1000        26   EMA     - RATIO OF TOTAL TO DOUBLE WHEEL MASS
     200 00        27   KU      - AMCD MASS SIZING PROPORTIONALITY FACTOR (METERS
PER SECOND)
     1 0000        28   NORDES  - NUMBER OF ORBITS BETWEEN DESATURATIONS
     500 00        29   MACS    - MASS OF ACS EXCLUDING AMCD ACTUATION ASSEMBLY (K
ILOGRAMS)
     1000 0        30   PACS    - POWER REQUIREMENT OF ACS EXCLUDING AMCD SPIN AXI
S (WATTS)
     2 6800        31   LM(1)   - MINIMUM LINEAR IMPULSE BIT WHEN CONTROLLING TORQ
```

If a change is desired, the following directions are given:

```
0ENTER 0 IF INPUT IS OK,
       1 TO CHANGE DATA ITEMS VIA THE KEYBOARD,
       2 TO ENTER A NEW TITLE,
    OR 9 TO RETURN TO THE EXEC
     ?
? 0
```

After a change is made, the entire input section will be displayed again for checkout and further modification if necessary.

The user is next asked if Category 2 (mass properties) inputs are to be checked.

```
0ENTER 1 IF YOU WISH TO REVIEW CATEGORY 2 INPUT ITEMS
       0 IF NOT
     ?
? 1
```

If it is desired to review these data, they will be displayed and optionally modified from:

```
1
+

 RCD CATAGORY 2 INPUT ITEMS

   6800 0          1  TWRM   - TOTAL WEIGHT OF THE SPACECRAFT EXCLUDING RCD (KILOGRAMS)
  0                2  BXM    - SPACECRAFT CENTER OF MASS FOR TWRM X  Y, Z COORDINATES
  0                3  BYM       RESPECTIVELY (CENTIMETERS)
   3078 0          4  BZM
  1 21800E+07      5  XXM    - MOMENT OF INERTIA XX FOR TWRM (KILOGRAM-METERS SQUARED)
  1 21800E+07      6  YYM    - MOMENT OF INERTIA YY FOR TWRM (KILOGRAM-METERS SQUARED)
  9 59000E+06      7  ZZM    - MOMENT OF INERTIA ZZ FOR TWRM (KILOGRAM-METERS SQUARED)
  0                8  PXYM   - PRODUCT OF INERTIA XY FOR TWRM (KILOGRAM-METERS SQUARED)
  0                9  PXZM   - PRODUCT OF INERTIA XZ FOR TWRM (KILOGRAM-METERS SQUARED)
  0               10  PYZM   - PRODUCT OF INERTIA YZ FOR TWRM (KILOGRAM-METERS SQUARED)
  -1 0000         11  KALKTK - PROP  TANK M  AND A  FLAG ()0 USER DEF , =0 PROP , (0 AUTO )
   3 0000         12  NOPROP - NUMBER OF PROPELLANT MASSES
  6 0000          13  NMAMCD - NUMBER OF AMCD MASSES
  8 0000          14  ANBAYS - ANALYSIS NUMBER OF BAYS
   123 00         15  NOGPAR - NUMBER OF GRIDPOINTS IN ANALYSIS (= NO  OF ROWS IN GPAREA)
OENTER 0 IF INPUT IS OK,
      1 TO CHANGE DATA ITEMS VIA THE KEYBOARD,
      2 TO ENTER A NEW TITLE,
   OR 9 TO RETURN TO THE EXEC
     ?
? 0
```

In the standalone mode, the following sequence will next be followed. The user will be prompted to supply the information requested from:

```
1
+

 INPUT FOR SOLAR PRESSURE CALCULATIONS

    100 00        1  A1L    - LENGTH OF AREA1 OF THE STRUCTURE (METERS)
    14 000        2  A1W    - WIDTH OF AREA1 OF THE STRUCTURE (METERS)
    21 000        3  A2L    - LENGTH OF AREA2 OF THE STRUCTURE (METERS)
    1 0000        4  A2W    - WIDTH OF AREA2 OF THE STRUCTURE (METERS)
  0               5  A3L    - LENGTH OF AREA3 OF THE STRUCTURE (METERS)
  0               6  A3W    - WIDTH OF AREA3 OF THE STRUCTURE (METERS)
  0               7  A4L    - LENGTH OF AREA4 OF THE STRUCTURE (METERS)
  0               8  A4W    - WIDTH OF AREA4 OF THE STRUCTURE (METERS)
    107 00        9  DIS    - DISTANCE, AREA1 CENTER MASS TO AREA2 CENTER MASS (METERS)
  0              10  BBETA  - BETA ANGLE (DEGREES)
    90 000       11  ALF    - VEHICLE ANGLE OF ATTACK (DEGREES)
OENTER 0 IF INPUT IS OK,
      1 TO CHANGE DATA ITEMS VIA THE KEYBOARD,
      2 TO ENTER A NEW TITLE,
      OR 9 TO RETURN TO THE EXEC
     ?
? 0
```

After the desired values have been specified the following outputs will be calculated and displayed.

```
THE SOLAR PRESSURE CONSTANT (NEWTONS/METER SQUARED) =  .46206E-05

   0THE TOTAL MOMENTUM IN THE VEHICLE REFERENCE FRAME
          ALONG THE X-AXIS(N-M-S)  =  0
          ALONG THE Y-AXIS(N-M-S)  =     .22428E+05
          ALONG THE Z-AXIS(N-M-S)  =  0

   0THE TOTAL SOLAR FORCE
          ALONG THE X-AXIS (NEWTONS)  =     .38761E+00
          ALONG THE Y-AXIS (NEWTONS)  =  0
          ALONG THE Z-AXIS (NEWTONS)  =     .15878E+01

   0THE TOTAL AERODYNAMIC FORCE
          ALONG THE X-AXIS (NEWTONS)  =     .28521E-01
          ALONG THE Y-AXIS (NEWTONS)  =  0
          ALONG THE Z-AXIS (NEWTONS)  =     .12432E-02

   0THE TOTAL EXTERNAL FORCE
          ALONG THE X-AXIS (NEWTONS)  =     .39898E+00
          ALONG THE Y-AXIS (NEWTONS)  =  0
          ALONG THE Z-AXIS (NEWTONS)  =     .15878E+01
```

After the previous information is given, the remaining output is written to file LPRINT for each orbital point. Following is an example for N = 2. A hardcopy listing of LPRINT may be obtained using the following commands after the RCD module is exited:

```
REWIND, LPRINT.
ASSIGN, MS, OUTPUT.
COPYSBF, LPRINT.
ROUTE, OUTPUT, DC = PR.
```

```
0FOR N - 2 THE SUM OF THE EXTERNAL TORQUES
                         IN THE X-DIRECTION = 0
                         IN THE Y-DIRECTION =     .40659E+00
                         IN THE Z-DIRECTION = 0


0FOR N   2 THE EULER ANGLE THETA    0
           THE EULER ANGLE PSI    = 0
           THE EULER ANGLE PHI    = 0


0FOR N   2 THE EULER RATE THETA1 =    .34929E 05
           THE EULER RATE PSI1   = 0
           THE EULER RATE PHI1   = 0


0      THE X COMPONENT OF THE GRAVITY GRADIENT TORQUE
                                      (NEWTON-METERS) =        0
       THE Y-COMPONENT OF THE GRAVITY GRADIENT TORQUE
                                      (NEWTON-METERS)          0
       THE Z COMPONENT OF THE GRAVITY GRADIENT TORQUE
                                      (NEWTON-METERS) =        0
```

•　　　　　　　　　　•

•　　　　　　　　　　•

•　　　　　　　　　　•

```
0      IN THE VEHICLE REFERENCE FRAME
       THE X COMPONENT OF THE MOMENTUM(N-M-S) = 0
       THE Y COMPONENT OF THE MOMENTUM(N-M-S) =    .84889E+02
       THE Z-COMPONENT OF THE MOMENTUM(N-M-S) = 0


0FOR N   2 THE AERODYNAMIC FORCE IN THE VEHICLE REFERENCE FRAME
           THE X-COMPONENT (NEWTONS) =  - .35099E-03
           THE Y COMPONENT (NEWTONS) =  0
           THE Z COMPONENT (NEWTONS)    0


0FOR N   2 THE AERODYNAMIC TORQUE IN THE VEHICLE REFERENCE FRAME
           THE X COMPONENT (NEWTON METERS) = 0
           THE Y COMPONENT (NEWTON-METERS) =    .69953E-02
           THE Z-COMPONENT (NEWTON-METERS) = 0


0THE SUM OF THE EXTERNAL FORCE
      IN THE X DIRECTION (NEWTONS) =  - .13411E-01
      IN THE Y-DIRECTION (NEWTONS) = 0
      IN THE Z-DIRECTION (NEWTONS) =    .76070E-02
```

In either mode, the user is now asked to give the name of the data base file for storage of the input configuraton.

```
ENTER NAME DATA BASE FILE IS TO BE REPLACED AS
   0 - DEFAULT FILE (LASSUR)
 OR N   PERMANENT FILE NAME
? RCDGYSA
```

At this point RCD module execution will terminate.

```
ENTER A 1 IF YOU WISH TO RUN ANOTHER CASE
OR A 0 IF NOT
```

2.8.3 RCD Module Programmer Information

The RCD module has been modified to permit operation in the stand-alone mode and to permit analysis of effects of solar pressure on the spacecraft system. Following is a description of the pertinent changes and description of key variables and arrays.

2.8.3.1 Common Modifications

Labeled common GENRL has been added to transfer data required for stand-alone operation. It is found in Block Data RCBLKD, subroutine INTCOM, subroutine QUIT, and new subroutine SOLPR. SHEAD, SITMS, SVARS, SDIM, SOLRIN, and SDSCRP are initialized in RCBLKD. They are used for transferrring stand-alone mode data to and from the LASS data base. To subroutine INTCOM has been added the code to read, display, and modify these data. These changes are inserted between cards INTCOM 159 and 160.

2.8.3.2 New Subroutines

Subroutine SOLRPR has been added to incorporate calculation of solar pressure-induced forces and torques and to permit independent calculation of torques due to gravity gradient and aero drag. The subroutine contains extensive commentation of the program variables and processes. The output data generated during execution of SOLRPP are displayed with code integral to SOLRPR.

The atmospheric pressure model has been changed to the 1976 U.S. Standard. Rather than calculate atmospheric density from empirical equations a linear interpolation routine is used to extract the logarithm (base 10) of the pressure as a function of altitude. Subroutine DVALT performs this function via a call to subroutine CVLN and then calculates density. The pressure versus altitude data are in DATA array PPVLT.

2.8.3.3 Plotting

To permit generation of total force and torque plots, SOLPPP contains calculations to determine vector sums in DO loop 2035. For each of the 61 orbital points, the area external forces and external torques are stored in the arrays defined in Table 2.8.3.1. Each array is derived from the component arrays shown in the table. The component arrays (1, N), (2, N), and (3, N) are the X, Y, and Z components respectively at the orbital point N. Definitions of title arrays and other text inputs for plot generation are described in program commentation.

TABLE 2.8.3.1. - ARRAY DEFINITION FOR OUTPUT PLOT GENERATION.

Array Name	Definition	Component Array
AMAG4	Total area exposed to solar pressure	AREA (3, 61)
AMAG5	Total force due to solar pressure	FORC (3, 61)
AMAG6	Total solar-induced torque	TORQ (3, 61)
AMAG7	Total gravity gradient torque	TGG (3, 61)
AMAG8	Total torque due to all effects	FXTRQ (3, 61)
AMAG9	Total cross product torque	TVC (3, 61)
AMAG10	Total torque in inertial frame	FXTRQI (3, 61)
AMAG11	Total momentum in inertial frame	MOMHI (3, 61)
AMAG12	Total momentum in vehicle frame	MOMHV (3, 61)
AMAG13	Total force due to aero drag	FA33 (3, 61)
AMAG14	Total torque due to aero drag	TA33 (3, 61)

For the modified model, the outputs generated will be as follows. If the original mode (TTSS) is selected, these outputs will not appear.

(1) The first outputs will be the area perpendicular to the sun in each direction during one orbit. The variables for this set of output are:

a. orbit point-N
b. anomaly angle (radians)-BETA (N)
c. area in the x-direction (meters-squared)-AREA (1, N)
d. area in the y-direction (meters-squared)-AREA (2, N)
e. area in the z-direction (meters-squared)-AREA (3, N)

(2) The second set of ouput will be the force that the solar pressure exerts on the vehicle during one orbit. The variables for this set of output are:

a. orbit point-N
b. anomaly angle (radians)-BETA (N)

c. force in the x-direction (Newtons)-FORC (1, N)

d. force in the y-direction (Newtons)-FORC (2, N)

e. force in the z-direction (Newtons)-FORC (3, N)

(3) The third set of output will be the torque exerted on the vehicle due to the solar pressure force during one orbit. The variables for this set of output as seen from left to right are:

a. orbit point-N

b. anomaly angle (radians)-BETA(N)

c. torque in the x-direction (Newton-meters)-TORQ (1, N)

d. torque in the y-direction (Newton-meters)-TORQ (2, N)

e. torque in the z-direction (Newton-meters)-TORQ (3, N)

(4) The rest of the output is printed for each separate orbit point (N). The output variables appear as follows:

a. The sum of the external torques (aerodynamic torques + solar pressure torques + gravity gradient torques - vehicle crossproduct torques) in the x-direction, y-direction and z-direction (newton meters)-EXTRQ (1, N), EXTRQ (2, N), EXTRQ (3, N) respectively.

b. The Euler angles generated (radians)-THETA, PSI, PHI.

c. The Euler rates generated by differentiation of the Euler angles (radians/second)-THETA1, PSI1, PHI1.

d. The generated gravity gradient torques in the x-direction, y-direction and z-direction (Newton-meters)-TGG (1, N,) TGG (2), TGG (3, N) respectively.

e. The generated vehicle cross-product torque in the x-direction, y-direction and z-direction (Newton-meters)-TVC (1, N), TVC (2, N), TVC (3, N) respectively.

f. The error generated by calculations in the x-direction, y-direction and z-direction (radians/second)-DELWX(N), DELWY(N), DELWZ(N) respectively.

g. The external torque in the inertial reference frame in the x-direction, y-direction and z-direction (Newton-meters) EXTPOI (1, N), EXTRQI (2, N), EXTPQI (3, N) respectively.

h. The momentum in the inertial reference frame in the x-direction, y-direction and z-direction (Newton-meter-seconds)-MOMHI (1, N), MOMHI (2, N), MOMHI (3, N) respectively.

i. The momentum in the vehicle referencce frame in the x-direction, y-direction and z-direction (Newton-meter-seconds)-MOMHV (1, N), MOMHV (2, N), MOMHV (3, N) respectively.

j. The aerodynamic force in the vehicle reference frame in the x-direction, y-direction and z-direction (Newtons)-FA33 (1, N), FA33 (2, N), FA33 (3, N).

k. The aerodynamic torque in the vehicle reference frame in the x-direction, y-direction and z-direction (Newton-meters) TA33 (1, N), TA33 (2, N), TA33 (3, N) respectively.

l. The sum of the external forces in the x-direction, y-direction and z-direction (Newtons)-FXTFPC (1, N), FXTTFPC (2, N), FXTFPC (3, N) respectively.

(5) The following totals are printed at the end of the output for N = 1-61. They are:

a. The total momentum in the vehicle reference frame summed for one complete orbit, in the x-direction, y-direction and z-direction (Newton-meter-seconds)-TMOMX, TMOMY, TMOMZ respectively.

b. The sum of the absolute value of the solar forces in th x-direction, y-direction and z-direction (Newtons)-TOTSLPY, TOTSLPY, TOTSLRZ respectively.

c. The sum of the absolute value of the aerodynamic forces in the x-direction, y-direction and z-direction (Newtons)-TOTAPOX, TOTAROY, TOTAPOZ respectively.

d. The absolute value of the sum of the solar plus aerodynamic forces in the x-direction, y-direction (Newtons)-TOTFCS, TOTFCY, TOTFCZ respectively.

2.8.3.4 Hard Coded Spacecraft Area Definition

Subroutine SOLPPR contains data that pertains exclusively to the reference 1 spacecraft. These data were defined previously in Table 2.8.2. To correctly calculate aerodynamic drag effects for other spacecraft the values of A11 through A32 and CD11 through CD32 must be changed to reflect the new model of interest. Also, the values of L11 through L32 must be changed to reflect the new lever arm created by the displacement of the center of pressure with respect to the center of mass.

2.9 APPENDAGE SYNTHESIZER MODULE

The Appendage Synthesizer (APSYN) allows the user to add interactively extra grids and elements to a structural model created by an automated model generator. The user may choose from several types of automatic element designers. The module creates an updated mass properties file for input to the Mass Properties Module and an updated dynamic analysis model file.

2.9.1 APSYN Technical Description

APSYN gets input from several sources. The model generators that interface with APSYN include the Box Ring, Radial Rib, Hoop and Column, and Contiguous Box Truss modules. These modules create two files used by APSYN:

(1) a mass properties file containing grid, element, and element properties data and (2) a NASTRAN dynamic model file. These data are read when APSYN begins execution. APSYN also reads data from a LASS data base and a dedicated input file. This special file contains four sets of data that specify the grids and elements to be added. The user reviews and alters this information as necessary.

Six element designs are available: ratio tube, Euler column, isogrid, truss, cable, and lattice mast. Each automated designer is given several input variables and calculates element member sizes and performance parameters. Ratio tube designs are based on element length, length to radius-of-gyration ratio, and diameter-to-thickness ratio. Fuler tubes are designed with a minimum wall thickness and Euler column buckling load. Isogrids are long, circular elements composed of a mesh-work of small struts. A truss is a long, triangular element composed of three corner members and several connecting struts.

The cable is designed as a solid rod under tension. The lattice element is similar to the truss except the lattice is deployed from a coiled or folded state inside a canister. Three types of lattice masts are available: (1) a coiled boom with continuous, elastic longerons; (2) a boom with articulated or folding longerons that rotates during deployment; and (3) a nonrotational boom with articulated longerons. Figures 2.9.1 through 2.9.3 illustrate these types of masts.

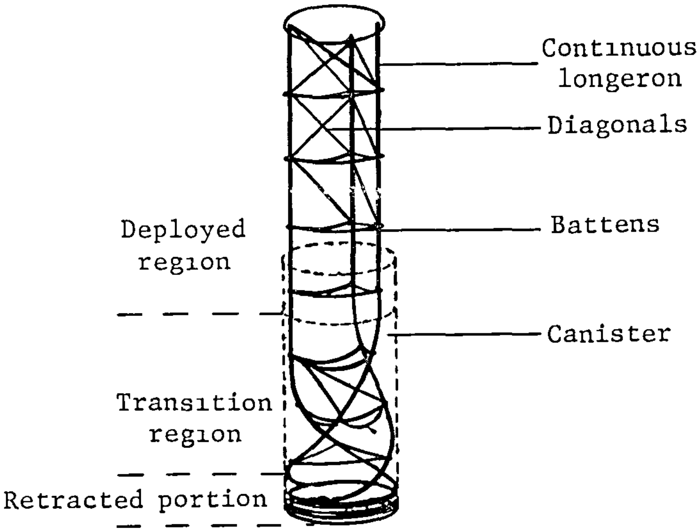


Figure 2.9.1. - Continuous-longeron mast.

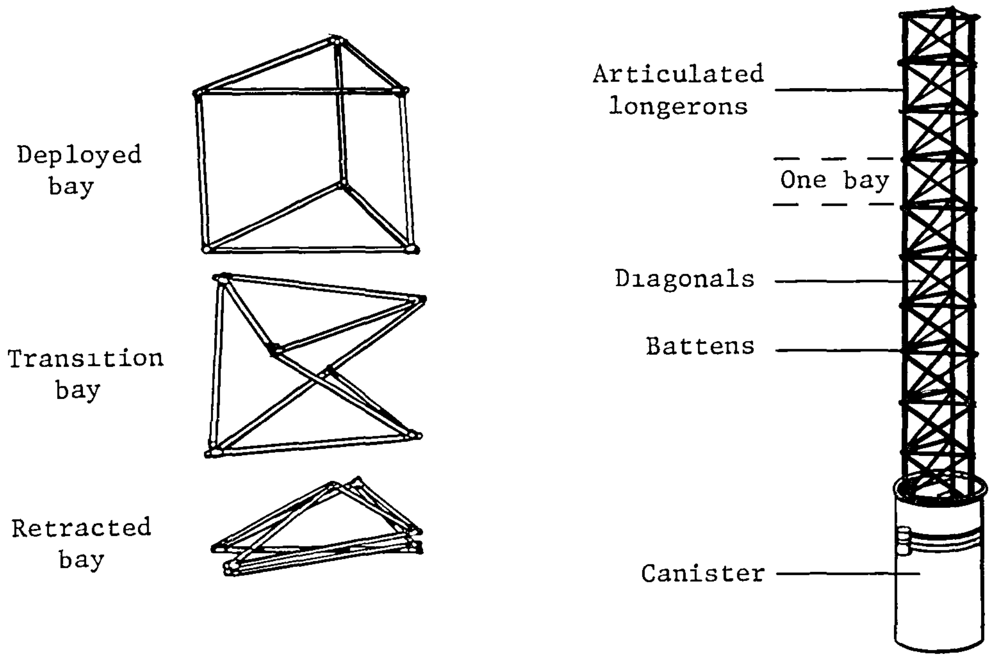


Figure 2.9.2. - Rotational, articulated-longeron mast.

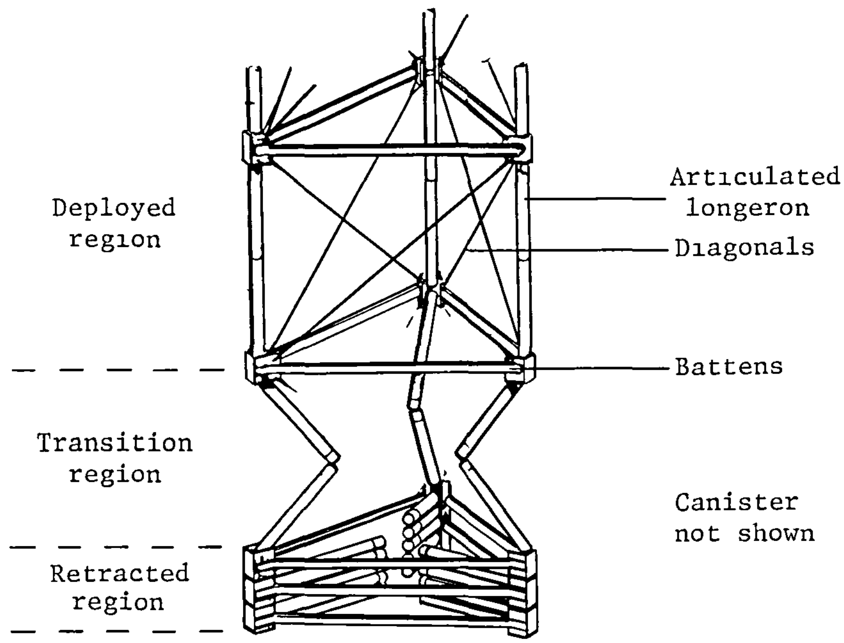


Figure 2.9.3. - Nonrotational, articulated-longeron mast.

Once all the elements are designed, APSYN updates the structural model and mass properties file to reflect the added grids and connectors.

2.9.2 APSYN User Instructions

The user directs APSYN during five major phases: (1) input file specification, (2) data base input, (3) APSYN file input, (4) element desing, and (5) output file specification.

2.9.2.1 Input File Specification

The user assigns the four input files through the following prompts:

```
WELCOME TO THE APPENDAGE SYNTHESIZER (APSYN)

FIRST, PLEASE SPECIFY THE FOLLOWING INPUT FILES
```

```
 ENTER DATA BASE FILE NAME
   (7 CHAR  MAX , 0 = DEFAULT OF LASSDB)
? APSDB

 ENTER NAME OF APSYN INPUT FILE
   (7 CHAR  MAX . 0 = DEFAULT OF ASMX)
? ASMX

 ENTER DYNAMIC MODEL FILE NAME
   (7 CHAR  MAX . 0 = DEFAULT OF DYNMOD)
? DYSDB

 ENTER MASS PROPERTIES FILE NAME
   (7 CHAR  MAX . 0 = DEFAULT OF MASSTN)
? MASSDB
```

After verifying each file exists, APSYN reads the structural model file and extracts needed information.

2.9.2.2 Data Base Input

Next, five variables are read from the data base:

```
 PLEASE STAND BY WHILE THE DYNAMIC MODEL IS READ

 NOW, PLEASE VERIFY THE FOLLOWING INPUT DATA
1
+          APPENDAGE SYNTHESIZER (APSYN) TEST CASE NO  1  -  10-23-81

 LASS DATA BASE INPUTS

     2 0000          1  NOGRID - NUMBER OF GRID POINTS ADDED (12 MAX)
     3 0000          2  NOCONN - NUMBER OF CONNECTING ELEMENTS ADDED (12 MAX)
     2 0000          3  NOMATL - NUMBER OF MATERIAL PROPERTY SETS ADDED (12 MAX)
     2 0000          4  NOSEPR - NUMBER OF SECTION PROPERTY SETS ADDED (12 MAX)
     2 0000          5  EFLERA - END FITTING LENGTH RATIO

 ENTER 0 IF INPUT IS OK,
       1 TO CHANGE DATA ITEMS VIA THE KEYBOARD,
       2 TO ENTER A NEW TITLE,
    OR 9 TO RETURN TO EXEC
? 0
```

EFLERA is used to add extra mass to the grid points at the ends of an element to approximate end connectors. This mass equals the mass of the whole connector times diameter divided by the product of length times EFLFRA.

2.9.2.3 APSYN File Input

The APSYN file contains matrices describing added: (1) nodes, (2) material property sets, (3) section property sets, and (4) elements. Each matrix is displayed and corrected sequentially.

The nodes matrix is first displayed

```
1
      APPENDAGE SYNTHESIZER (APSYN) TEST CASE NO  1  -  10-23-81                                      NODES  MATRIX

                             1            2           3
  ROW     EQUIV  ID       X (M)        Y (M)       Z (M)
    1       429    0                 11 500      100 00
    2       430    0                -11 500      100 00

 ENTER 0 IF INPUT IS OK,
       1 TO CHANGE DATA ITEMS VIA THE KEYBOARD,
       2 TO ENTER A NEW TITLE,
       3 TO CHANGE THF NUMBER OF ROWS IN NODES ,
    OR 9 TO RETURN TO THE EXEC
? 0
```

The equivalent ID is found by adding one to the largest node number found in the structural mode. The coordinates are based on the system used by the model generator that first produced the model.

Next, the materials matrix is shown:

```
1
4       AFFENDAGE SYNTHESIZER (APSYN) TEST CASE NO  1  -  10-23-81                                  MATRLS MATRIX

               1           2           3            4            5             6           7
  ROW    Y MOD-N/M2  THRMEX-1/K  DENS-KG/M3  STRES-N/M2  SHEAR-N/M2  L MOD-N/M2  LDEN-KG/M3

    1    1 38000E+11 0           15357       7 14000E+08 2 06000E+10 0           0
    2    1 34000E+11 0           1939 0      7 14000E+08 1 23789E+10 0           0

 ENTER 0 IF INPUT IS OK,
       1 TO CHANGE DATA ITEMS VIA THE KEYBOARD,
       2 TO ENTER A NEW TITLE,
       3 TO CHANGE THE NUMBER OF ROWS IN MATRLS,
    OR 9 TO RETURN TO THE EXEC
? 0
```

where	Y.MOD	-	Young's modulus of elasticity,
	THRMEX	-	Thermal expansion coefficient,
	DENS	-	Actual density,
	STRES	-	Maximum design stress,
	SHEAR	-	Shear modulus,
	L.MOD	-	Young's modulus for truss lacing (element type 2),
	L.DEN	-	Density of lace (element type 2).

Each added element must have a set of material properties found in this matrix.

The properties for a lattice mast (type 4) should not be filled in but a separate row must be provided.

The section properties matrix follows:

```
1
+       APPENDAGE SYNTHESIZER (APSYN) TEST CASE NO  1  -  10-23-81                                   SECTON MATRIX

                1          2           3           4
  ROW     MIN THK-M   MIN DIA-M    L/ROG        DIA/THK

     1    3 00000E-03 3 00000E-02  200 00       100 00
     2    4 00000E-04 1 00000E-02  300 00       100 00

 ENTER 0 IF INFUT IS OK,
       1 TO CHANGE DATA ITEMS VIA THE KEYBOARD,
       2 TO FNTER A NEW TITLE,
       3 TO CHANGF THE NUMBER OF ROWS IN SECTON,
    OR 9 TO RETURN TO THE EXEC
? 0
```

where	MIN THK	-	Minimum allowable wall thickness,
	MIN DIA	-	Minimum allowable tube diameter,
	L/ROG	-	Length over radius of gyration,
	DIA/THK	-	Diameter over thickness ration.

These design parameters are not required for the lattice mast designer, but a separate row must be provided.

Finally, the elements matrix is displayed:

```
1
+       APPENDAGE SYNTHESIZER (APSYN) TEST CASE NO  1  -  10-23-81                                                          ELEMTS MATRIX
```

ROW	1 GRID1	2 GRID2	3 CONTYPE	4 ADD MASS/M	5 MATL ID	6 SECT ID	7 DES LOAD-N	8 PRE LOAD-N	9 INT NODES	10 PIN FLAGS
1	101 00	429 00	4 0000	0	1 0000	1 0000	2000 0	0	0	3 0000
2	429 00	430 00	2 0000	0	2 0000	2 0000	1000 0	0	0	3 0000
3	430 00	115 00	4 0000	0	1 0000	1 0000	2000 0	0	0	3 0000

```
 ENTER 0 IF INPUT IS OK,
       1 TO CHANGE DATA ITEMS VIA THE KEYBOARD,
       2 TO ENTER A NEW TITLE,
       3 TO CHANGE THE NUMBER OF ROWS IN ELEMTS,
    OR 9 TO RETURN TO THE EXEC
? 0
```

where: Grid 1 - First grid point;

Grid 2 - Second grid point;

CONTYPE - Connector type:

0 = Ratio tube,

1 = Euler column,

2 = Isogrid,

3 = Truss,

4 = Lattice Mast,

5 = Cable,

6 = Pepeat previous row with different grids;

ADD MASS/M - Added mass per meter of connector (in addition to connector mass);

MATL ID - Material property set number (row in MATRLS matrix);

SECT ID - Section property set number (row in Section matrix);

DES. LOAD - Axial compressive design load in N (not needed for lattice mast type 4);

PPE.LOAD - Cable tension in N (element type 5 only)

INT NODES - Number of interal nodes;

PIN FLAGS - Connection flag:

0 = Both ends fixed;

1 = End 1 is pinned and Fnd 2 is fixed;

2 = End 1 is fixed and Fnd 2 is pinned;

3 = Both ends pinned.

At least one of the grids must exist in the structural model.

This matrix completes the input section of APSYN.

2.9.2.4 Flement Design

The elements are designed based on the information just supplied. Those elements loaded with an axial load are designed first, followed by elements that can resist a torque. Ratio tubes, Euler columns, cables, trusses, and isogrids are designed automatically from the variables specified in previous sections. Several key parameters are printed for each element as shown:

```
TRUSS COLUMN DESIGNED BY AXIAL LOAD-METRIC
PCR= 60000E+04  L= 20000E+03  SR= 21534E+03  WT= 31827E+00
W  = 63654E+02  H= 19702E+01  I= 40000E-03   N= 91
RHOC= 16330E+04  EC= 25900E+12  RHOD= 16330E+04  ED= 11000E+12

LC = 21978E+01       LD = 31632E+01       LP = 22750E+01
AC = 36283E-04       AD = 22223E-05       AP = 21770E-04
RC = 14636E-01       RD = 16821E-02       RP = 88618E-02
 THIN WALL            SOLID ROD            THIN WALL
L/R= 21528E+03
SC = 55123E+08
SCR= 55156E+08
D/T= 73182E+02

ISOGRID COLUMN DESIGNED BY AXIAL LOAD METRIC OUTPUT

PCR  =  60000E+04     AL   =  59190E+03     R    =  24980E+01
A    =  24491E+00     B    =  18981E-02     D    =  18770E-02
TBAR =  50393E-04     ROD  =  21485E-02     W/L  =  12916E+01
CPCR =  60000E+04     GAMA =  19110E+00     E    =  25900E+12
CFIX =  17800E+01     RHO  =  16330E+04     N    =         74
FTOT =  58699E+04     STR  =  22264E+08     BETA =  77503E-02
BLES =  69729E-01
```

```
EULER TUBE DESIGNED BY AXIAL LOAD AND MINIMUM DIMENSIONS-METRIC
     LOAD=  10000E+04LENGTH=  10460E+03DIA =  30098E+00
     THICK =  40000E-03AREA AXIAL=  37822E-03AREA MOM =  42826E-05
     WT =  64604E+02

TENSION CABLE DESIGNED BY LOAD OVER STRESS ALLOWED-METRIC
     LOAD=  20000E+04LENGTH=  68990E+03STRESS ALLOWED=  11000E+09
     DIA=  48114E-02WT =  18402E+02
```

The lattice mast designer runs interactively by asking a series of questions. First, the user specifies the type of mast:

```
NOW COMES THE DESIGN OF ADDED ROD ELEMENTS

THIS IS THE LATTICE MAST DESIGNER

SELECT TYPE OF LATTICE MAST
  1 - CONTINUOUS LONGERONS,
  2 - ARTICULATED ROTATIONAL LONGERONS,
  3 - ARTICULATED NON-ROTATIONAL LONGERONS
? 1
```

These types correspond to those discussed in Section 2.9.1. The mast material is selected next:

```
SELECT LATTICE MAST MATERIAL
  1 - S GLASS,
  2 - HTS GRAPHITE,
  3 - 7075 - T6 ALUMINUM,
  4 - TI - 6AL - 4V TITANIUM
? 2
```

The maximum allowable diameter of the mast is input as:

```
ENTER MAXIMUM STOWED DIAMETER (METERS)
? 1 0
```

Next, a critical sizing parameter is chosen:

```
SELECT TYPE OF PERFORMANCE PARAMETER
  1 - USE DIAMETER AS IS,
  2 - CHECK BENDING STIFFNESS,
  3 - CHECK CRITICAL BENDING MOMENT,
  4 - CHECK ALLOWABLE COMPRESSION,
  5 - CHECK MASS PER UNIT LENGTH
? 1
```

For continuous longeron masts, input of 1 instructs the program to proceed directly to performance calculation.

Choices 2 through 5 require the corresponding quantity to be entered:

```
ENTER BENDING STIFFNESS (EI, N-M2)
? 1E4
```

The mast diameter required for this performance is calculated and limited to the maximum allowable diameter. For articulated longeron masts (type 2 and 3), a choice of 1 instructs the program to request longeron sizes:

```
ENTER LONGERON WALL THICKNESS (M, 0 - DEFAULT OF 6.35E-4 M)
? 0
```

Choices 2 through 5 require input of the appropriate quantity in addition to longeron wall thickness:

```
ENTER LONGERON DIAMETER (M)
?  .05
```

For articulated masts, longeron diameter, not mast diameter, is sized by these parameters and used to calculate performance.

Finally, the resulting mast characteristics are printed:

```
HERE ARE THE RESULTING MAST CHARACTERISTICS FOR A
CONTINUOUS LONGERON MAST

   MAST DIAMETER (M) =    1000E+01
   LONGERON WALL THICKNESS (M) = 0
   LONGERON DIAMETER (M) =    5000E-02
   MAST CROSS-SECTIONAL AREA (M2) =    5891E-04
   DEPLOYED LENGTH (M) =    9873E+02
   DEPLOYMENT FORCE (N) =    2466E+02
   STOWED LENGTH (M) =    9429E+00
   CANISTER LENGTH (M) =    9429E+00
   MASS PER UNIT LENGTH (KG/M) =    2933E+00
   TOTAL MASS (KG) =    2896E+02
   MODULUS OF ELASTICITY (N/M2) =    1340E+12
   BENDING STIFFNESS (NM2) =    9866E+06
   STOWED STRAIN LIMIT (M/M) =    5000E-02
   ACTUAL MATERIAL DENSITY (KG/M3) =    1660E+04
   EFFECTIVE MATERIAL DENSITY (KG/M3) =    4980E+04
   AREA MOMENT OF INERTIA (M4) =    7363E-05
   TORSIONAL STIFFNESS (NM2) =    9114E+05
   SHEAR STIFFNESS (N) =    7292E+06
   CRITICAL BENDING MOMENT (NM) =    7789E+02
   EULER COLUMN COMPRESSION (N) =    9990E+03
   ALLOWABLE COMPRESSION (N) =    3116E+03
   SHEAR STRENGTH (N) =    3853E+02
   TORSIONAL STRENGTH (NM) =    1665E+02
```

2.9.2.5 Output File Specification

The user specifies the file names where the updated output is stored:

```
 ENTER NAME OF UPDATED DATA BASE FILE
   (7 CHAR MAX, 0 = DEFAULT OF LASSDB)
? APSDB

 ENTER NAME OF UPDATED APSYN MATRIX FILE
   (7 CHAR MAX, 0 = DEFAULT OF ASMX)
? ORMX
```

```
ENTER NAME OF UPDATED DYNAMIC MODEL FILE
  (7 CHAR MAX, 0 = DEFAULT OF DYML)
? [illegible]

ENTER NAME OF UPDATED MASS PROPERTIES FILE
  (7 CHAR MAX, 0 = DEFAULT OF MASSOUT)
? MAS[illegible]
```

Once the files are updated, the module is finished.

2.9.3 APSYN Programmer Instructions

The APSYN program is divided into an input overlay (1,0), a computation overlay (2,0), and an output overlay (3,0). Each of these prime overlays is called sequentially by the main overlay (0,0). Table 2.9.1 summarizes the input and output files used by the program and Table 2.9.2 summarizes the external routines needed.

TABLE 2.9.1 - APSYN INPUT AND OUTPUT FILES.

Local Name	Permanent Name	Function
TAPE 8	ASMX	APSYN matrices
TAPE 11	DYML	Updated dynamic model
TAPE 10	DYNMOD	Input dynamic model
TAPE 49	INPUT	Terminal input
TAPE 14	LASSDB	Data base
TAPE 4	LFLAGS	Certain program variables
TAPE 7	LPRINT	Data base and APSYN matrix printout
TAPE 9	LPRINT	Data base and APSYN matrix printout
TAPE 9	MASSIN	Mass properties input
TAPF 9	MASSOUT	Mass properties output
TAPE 50	OUTPUT	Terminal output
TAPE 0	-	Dummy file required by TSFND

TABLE 2.9.2. - REQUIRED LIBRARY ROUTINES.

Routine name	Library name	Function
ASBLKD	APSLIB	Block data initializer
BILDTM	APSLIB	Add note to TM Matrix
CABLE	APSLIB	Design cable element
CALCW	APSLIB	Calculate truss mass
CHKINP	APSLIB	Check input variables
CHNGIM	LASSLIB	Change input matrix
CHNGIN	LASSLIB	Change data list
CLOSE	LASSLIB	Terminate program
CUBIC	APSLIB	Solve cubic equation
ELDS	APSLIB	Element designer
EUTU	APSLIB	Design Euler tube
ISTU	APSLIB	Design isogrid column
LATTICE	APSLIB	Design lattice mast
LEFT	LASSLIB	Left-shift and zero-fill string
LENGTH	APSLIB	Calculate element length
LINE GP	APSLIB	Get array line in GPAREA
LINETM	APSLIB	Get array line in TM
NEWTERM	APSLIB	Pause and clear screen
PFM	LASSLIB	Permanent file manager
PRNTGP	APSLIB	Print grid point matrix
PRNTIM	LASSLIB	Print matrix
RATU	APSLIB	Ratio tube designer
RDDTBS	LASSLIB	Read data base
RDINPM	LASSLIB	Read input matrix
SECT	APSLIB	Get section properties
SETELM	LSSLIB	Add element to IELM
SETNOD	LSSLIB	Add node to GRIDD
TRUS	APSLIB	Truss column designer
WRDTBS	LASSLIB	Write to data base
WRMBCD	LASSLIB	Write output matrix

2.9.3.1 Input Overlay (1,0)

Overlay (1,0) functions to get file names; scan the dynamic model; display and alter information from the data base, APSYN input files, and mass properties file; and set certain node and element numbering variables. The dynamic model is scanned in overlay (1,1) and data base APSYN input and mass properties information is handled in overlay (1,2). The rest of the processing occurs in the primary overlay.

The main purpose of reading the dynamic model is to determine what node, element, material, and property identification numbers are already used in the existing model. Thus, new items can be added independently of the present numbering scheme. The source code for overlay (1,1) thoroughly documents the variables extracted from the model.

Overlay (1,2) reads, prints, and changes information from the data base and the APSYN input file. The APSYN file contains four sets of data: node locations, material property sets, section property sets, and element parameters. Also, node, element and property information is loaded from the mass properties file into local arrays. These arrays are documented in the programmer instruction sections of the automated model generators.

2.9.3.2 Computation Overlay (2,0)

Overlay (2,0) calls three secondary overlays: nodes are processed in overlay (2,1), elements are processed in overlay (2,2), and masses are processed in overlay (2,3).

In overlay (2,1), external and internal nodes generated by the program are added to three local arrays (GPAREA, TM, and GRIDD). At least one of these nodes must be from the structural model or a fatal error will occur. New GRID cards are added to the dynamic model.

Overlay (2,2) calls ELDS, a library routine, which designs each added element. ELDS calls the appropriate element designer and adds PROD and PBAR cards to the dynamic model. Overlay (2,2) writes CROD, CBAR, and MAT1 cards and updates the IELM and TUBP arrays.

Overlay (2,3) transfers the partially updated dynamic model from TAPE 10 to TAPE 11. As this occurs, existing concentrated mass cards, CONM2, are updated and new cards are added. This completes the dynamic model.

2.9.3.3 Output Overlay (3,0)

Overlay (3,0) writes program information to temporary files and transfers the temporary files to permanent storage. These files include the data base, the four APSYN matrices, the dynamic model, and the mass properties. The data base and APSYN information is also written to local file LPRINT, which can be copied to a hard copy device after the running of the program.

2.10 CONTROL BANDWIDTH ESTIMATION

This program computes the approximate control system bandwidth requirement for the rigid body case to meet specified pointing limits for an Earth-oriented mission similar to a radiometer. These data are useful as a measure of the degree of difficulty of the control problem and, when compared to the frequencies of the spacecraft structural modes, provide a good measure of the extent to which flexibility will be a problem. As a general rule, if the required bandwidth is less than the first mode of the spacecraft, then flexibility can be expected to play a minor role.

2.10.1 Control Bandwidth Technical Description

The distrubance sources considered in this program are slew command, aerodynamic pressure effects, and solar pressure effects. In calculating the bandwidth requirements, the spacecraft is considered to be rigid. The minimum fuel approach provides the widest bandwidth system and is used for the present program.

The controls approach used in the bandwidth program is based on a second order system, and the bandwidth requirements are derived from these equations. The bandwidth expressions contained in the source code are for minimum fuel slew command, constant orbit rate terms for both aerodynamic and solar torques, twice orbit rate aerotorques, and the step component of the solar torque. The bandwidth requirements for each contributing disturbance are calculated successively and compared with the previous bandwidth determination. The largest value of this comparison is replaced in the variable BMAX. The program then continues to the next bandwidth driver.

Development of the bandwidth equations are presented in Reference 5.

2.10.2 Control Bandwidth User Information

The user inputs are entered after being prompted by the UIN subroutine. The first prompt requires selection of input mode from:

```
DO YOU WISH TO USE DEFAULTS OR INPUT INTERACTIVELY
? DI
```

If the default values are to be used the program will calculate and output the following.

```
 ALTITUDE =        100000E+04 CLOSED LOOP DAMPING =      0

                                  X              Y              Z

SLEWTIME                  0              0                   300000E+03
DESIGNATE ANGLE           0              0                   450000E+02
LIMIT ANGLE                  500000E-02     500000E-02     500000E-02
INERTIA                      382000E+06     421000E+08     426000E+08
DRAG TORQUE (W=0)         0                 200000E+01  0
DRAG TORQUE (W=WORB)      0                 300000E+01  0
DRAG TORQUE (W=2*WORB)    0              0              0
SOLAR TORQUE (STEP)       0                 500000E+00     500000E+00
SOLAR TORQUE (SINE)       0                 500000E+00     500000E+00

 POINTING BANDWIDTH          0              0                 200000E+00
POINTING TORQUE           0              0                   148702E+04
AERO BANDWIDTH (0)        0                 233319E-01  0
AERO BANDWIDTH (1)        0                 285756E-01  0
EROR BANDWIDTH (2)        0              0              0
SOLAR BANDWIDTH (STEP)    0                 164982E-01     164010E-01
SOLAR BANDWIDTH (SINE)    0                 116658E-01     115971E-01
GRAVITY BANDWIDTH            113976E-03 0              0
REQUIRED RIGID BODY BW    0                 456267E-01     319340E+00
```

If the defaults are not desired data are input interactively. Successful entry of data is required for advancement to the next prompt, otherwise the error message, "IMPROPER/INCOMPLETE ENTRY...TRY AGAIN", is printed and the data prompt redisplayed. Following is an example of the interactive input sequence.

```
 DO YOU WISH TO USE DEFAULTS OR INPUT INTERACTIVELY
? INT
 ENTER ALTITUDE IN MILES
? 1000
 ENTER CLOSED LOOP DAMPING
? .5


 ENTER SLEW TIME FOR EACH COORDINATE AXIS
 (SEPERATE EACH VALUE BY A COMMA)
? 0,0,300
```

```
 ENTER DESIRED ANGLE FOR EACH COORDINATE AXIS
 (SEPERATE EACH VALUE BY A COMMA)
? 0,0,45

 ENTER THE LIMIT ANGLE FOR EACH COORDINATE AXIS
 (SEPERATE EACH VALUE BY A COMMA)
?  005, 005, 005

 ENTER THE INERTIA FOR EACH COORDINATE AXIS*
 (SEPERATE EACH VALUE BY A COMMA)
? 3417,4417,4417

 ENTER THE CONSTANT AERODYNAMIC DRAG TORQUE
 (SEPERATE EACH VALUE BY A COMMA)
? 0,1,0

 ENTER THE ORBIT RATE AERODRAG TORQUE
 (SEPERATE EACH VALUE BY A COMMA)
? 0.1,0

 ENTER THE TWICE ORBIT RATE AERO TORQUE*
 (SEPERATE EACH VALUE BY A COMMA)
? 0,0,0

 ENTER ORBIT RATE COMPONENT OF SOLAR TORQUE
 (SEPERATE EACH VALUE BY A COMMA)
? 0,2,2

 ENTER THE SOLAR STEP TORQUE*
 (SEPERATE EACH VALUE BY A COMMA)
? 0, 5, 5
```

Following the last question, the calculations are performed and both the input and computed output variables are displayed as shown here.

ALTITUDE = 100000E+04 CLOSED LOOP DAMPING = 500000E+00

	X	Y	Z
SLEWTIME	0	0	300000E+03
DESIGNATE ANGLE	0	0	450000E+02
LIMIT ANGLE	500000E-02	500000E-02	500000E-02
INERTIA	300000E+08	400000E+08	400000E+08
DRAG TORQUE (W=0)	0	100000E+01	0
DRAG TORQUE (W=WORB)	0	100000E+01	0
DRAG TORQUE (W=2*WORB)	0	0	0
SOLAR TORQUE (STEP)	0	500000E+00	500000E+00
SOLAR TORQUE (SINE)	0	200000E+01	200000E+01
POINTING BANDWIDTH	0	0	200000E+00
POINTING TORQUE	0	0	139626E+04
AERO BANDWIDTH (0)	0	169257E-01	0
AERO BANDWIDTH (1)	0	169256E-01	0
AERO BANDWIDTH (2)	0	0	0
SOLAR BANDWIDTH (STEP)	0	129071E-01	129071E-01
SOLAR BANDWIDTH (SINE)	0	239365E-01	239365E-01
GRAVITY BANDWIDTH	0	0	0
REQUIRED RIGID BODY BW	0	382194E-01	319340E+00

The user is then prompted to terminate module execution or to perform another analysis.

2.10.3 Control Bandwidth Programmers Information

The bandwidth estimation program BNDREQ consists of the primary program and three subroutines (UIN BNDWTH, UOUT). The main program acts as executive and calls the other subroutines as they are required.

The UIN subroutine is a user friendly interactive routine that prompts the user for input data. The input variables are defined as follows:

ALT	Altitude of spacecraft (miles)
CLDAMP	Closed loop damping
SLEWT(I)	Slew time for each axis (I = 1,3) (sec)
ADDES(I)	Desired slewing angle for each axis (I = 1,3) (degrees)
ADLIM (I)	Limit or error angle (degrees)
INERTIA(I)	Spacecraft inertia ($kg\text{-}m^2$)
TDRAG	Constant, orbit rate, twice orbit rate term for x, y, z axis (N-m)
TSTEP	Step torque due to eclispe (N-m)
TSINE	Solar torque, orbit rate (N-m)

The data input is entered by the user, and is checked for reasonableness and out-of-bound conditions. The input variables are passed between subroutines in the common /IN/ block. If an error or invalid value is detected, an appropriate error message is printes. if CLDAMP = 0, its value is changed to $\sqrt{2}/2$ for critical closed loop damping.

The subroutine UOUT is the user output routine. the subroutine formats and outputs the user input specifications and the resultant control bandwidth requirements as computed by subroutine BNDWITH.

The BNDWTH subroutine computes the required pointing torque control bandwidths and maximum equivalent rigid body bandwidth. BWDWTH always returns an answer. If torque or bandwidth requirement comes back zero, it means that there is no requirement in this component direction. The output calculations are passed back to the main program BNDREQ via COMMON/OUT/.

3.0 DATA FILE DESCRIPTION

This section lists and describes data files generated and used with the modules described in Section 2.0. These files fall into two categories, those using the LASS data base architecture and those using host computer (CDC) local files and file management. The files used with each module for initial test and acceptance runs are listed for each module in Table 3.1. To execute a module requires typing BEGIN,, (procedure file name) with the procedure file name found in Table 3.1. These procedure files are on user ID 262597C on the CDC system.

Table 3.1. - MODULE FILES USED FOR TEST RUNS.

Module	Procedure file	Input file(s)	Output file(s)
Box ring	BRPROC	GR28BOX	GR28BOX, DY28GR, MAS28GR
Contiguous truss	LSSCTPR	ASSACT	ASSACT, DYCT, MASSCT
Radial rib	RRPROC	ASSARHF	ASSARHF, DYRIBHF, MRIBHF
Hoop & column	HCPROC	ASSAHC	ASSAHC, DYHC, MASSHC
Mass properties	MPPROC	GR28BOX DYAPS MASSOUT	DYASSA, MASASSA
Orbital transfer	OTPROC	none	none
Rf analysis	RFPROC	none	none
RCD	LASSE	RCDTEST	RCDTEST
Appendage Synthesizer	APSPROC	APSBR APMX DYGR28 MPGR28	APSBR APMX DYAPS MASSOUT

The dynamic model files are written for interfacing with NASTRAN. Records in different files have the same general format. Examples of dynamic model files are found at the end of this section.

The mass properties matrices files contain element and grid information consisting of arrays IELM, GRIDD, TUBP, and single variables NFL and NG. The data written to these files is unformatted and listings are therefore not included here. The data is similar to that contained in the associated dynamic model file.

Listing of the other files listed in Table 3.1 can be obtained at LaRC by retrieving files from User ID 262597C on the LaRC CDC computer system. Following is an example showing how to obtain a listing of the file DYCT on a hardcopy terminal.

```
GET,DYCT/UN=262597C
COPY, DYCT
```

If a hardcopy is desired from a printer (as might be the case when using a CRT) the procedure is:

```
GET, (file name)/UN=262597C
ASSIGN, MS, OUTPUT
COPYSBF, (file name)
ROUTE, OUTPUT, DC=PR
```

Following are listings of the procedure files and the formatted dynamic model files for each of the model generators. The file DYASSA is the final result of the Box Ring model. It is created by adding to DY28GR in both the mass properties and appendage synthesizer modules. Listing DY28GR or DYAPS would be redundant.

PROCEDURE FILE LISTINGS

```
 COPY,BRPROC
 PROC,RREX
RETURN,*,XEDIT
MAP,OFF
GET,LASSLIB,AVIDLIB/UN=403180N
GET,RAUSYS/UN=727850N
SETCORE,ZERO
GET,NMACFTN/UN=LIBRARY
LIBRARY,NMACFTN
ATTACH,LIBFTEK/UN=LIBRARY
GET,LASSBR
FTN,I=LASSBR,L=T
LDSET,LIB=LASSLIB/FORTRAN/AVIDLIB/RAUSYS/LIBFTEK,PRESETA=0
LGO
DAYFILE,OP=I,DAY
REPLACE,DAY
EXIT
REWIND,DAY
DAYFILE,OP=I,DAY
REPLACE,DAY
REVERT,RREX
 EOI ENCOUNTERED
/
```

```
 COPY,HCPROC
 PROC,RREX
GET,LASSLIB,AVIDLIB/UN=403180N
RETURN,LGO,T,HOOPC,TAPE2,TAPE8
GET,RAUSYS/UN=727850N
SETCORE,ZERO
GET,NMACFTN/UN=LIBRARY
LIBRARY,NMACFTN
ATTACH,LIBFTEK/UN=LIBRARY
GET,HOOPCOL
FTN,I=HOOPCOL,L=T
LDSET,LIB=LASSLIB/FORTRAN/AVIDLIB/RAUSYS/LIBFTEK,PRESETA=0
LGO
DAYFILE,OP=I,DAY
REPLACE,DAY
EXIT
REWIND,DAY
DAYFILE,OP=I,DAY
REPLACE,DAY
REVERT,RREX
 EOI ENCOUNTERED
/
```

```
 COPY,LSSCTPR
 PROC,LSSCTPR
DELIVER     DERYRDER     1232
GET,LASSLIB,AVIDLIB/UN=403180N
MAP,OFF
RETURN,TAPE2,TAPE8
REWIND,LGO,T
REWIND,BOXGEN
GET,RAUSYS/UN=727850N
SETCORE,ZERO
GET,NMACFTN/UN=LIBRARY
LIBRARY,NMACFTN
ATTACH,LIBFTEK/UN=LIBRARY
GET,LSSCT
FTN,I=LSSCT,L=T
LDSET,LIB=LASSLIB/FORTRAN/AVIDLIB/RAUSYS/LIBFTEK,PRESETA=0
LGO
DAYFILE,OP=I,DAY
REPLACE,DAY
EXIT
REWIND,DAY
DAYFILE,OP=I,DAY
REPLACE,DAY
REVERT,RREX
 EOI ENCOUNTERED
/
```

```
 COPY,APSPROC
 PROC,RREX
RETURN,*,XEDIT
GET,LASSLIB,AVIDLIB,RAUSYS
MAP,OFF
SETCORE,ZERO
GET,NMACFTN/UN=LIBRARY
LIBRARY,NMACFTN
ATTACH,LIBFTEK/UN=LIBRARY
GET,APSMAIN,A=APSLIB
FTN,I=APSMAIN,L=T
LDSET,LIB=LASSLIB/FORTRAN/AVIDLIB/A/RAUSYS/LIBFTEK,PRESETA=0
LDSET,USEP=APBLKD
LGO
DAYFILE,OP=I,DAY
REPLACE,DAY
EXIT
REWIND,DAY
DAYFILE,OP=I,DAY
REPLACE,DAY
REVERT,RREX
 EOI ENCOUNTERED
/
```

```
 COPY,LASSI
 PROC,RREX
GET,LASSLIB,AVIDLIB/UN=403180N
REWIND,*
GET,RAUSYS/UN=727850N
MAP,OFF
SETCORE,ZERO
GET,NMACFTN/UN=LIBRARY
LIBRARY,NMACFTN
ATTACH,LIBFTEK/UN=LIBRARY
GET,RCDLIB,MAINRCD
FTN,I=MAINRCD,L=T
LDSET,LIB=LASSLIB/FORTRAN/AVIDLIB/RAUSYS/LIBFTEK/RCDLIB,PRESETA=0
LDSET,USEP=RCBLKD
LGO
DAYFILE,OP=I,DAY
REPLACE,DAY
EXIT
REWIND,DAY
DAYFILE,OP=I,DAY
REPLACE,DAY
REVERT,RREX
 EOI ENCOUNTERED
/



COPY,RRPROC
 PROC,RRPROC
DELIVER     DERYRDER     1232
RETURN,*,XEDIT
GET,LASSLIB,AVIDLIB,RAUSYS
MAP,OFF
SETCORE,ZERO
GET,NMACFTN/UN=LIBRARY
LIBRARY,NMACFTN
ATTACH,LIBFTEK/UN=LIBRARY
GET,RADRIB
FTN,I=RADRIB,L=T
LDSET,LIB=LASSLIB/FORTRAN/AVIDLIB/RAUSYS/LIBFTEK,PRESETA=0
LGO
DAYFILE,OP=I,DAY
REPLACE,DAY
EXIT
REWIND,DAY
DAYFILE,OP=I,DAY
REPLACE,DAY
REVERT,RREX
 EOI ENCOUNTERED
/
```

```
 COPY,MEPROC
 PROC,RREX
RETURN,*,XEDIT
GET,LASSLIB,AVIDLIB/UN=403180N
MAP,OFF
GET,RAUSYS/UN=727850N
GET,NMACFTN/UN=LIBRARY
LIBRARY,NMACFTN
ATTACH,LIBFTEK/UN=LIBRARY
GET,MASNEW1
FTN,I=MASNEW1,L=T
LDSET,LIB=LASSLIB/FORTRAN/AVIDLIB/RAUSYS/LIBFTEK,PRESETA=0
LGO
DAYFILE,OP=I,DAY
REPLACE,DAY
EXIT
REWIND,DAY
DAYFILE,OP=I,DAY
REPLACE,DAY
REVERT,RREX
 EOI ENCOUNTERED
/
```

```
 COPY,REPROC
 PROC,RREX
GET,LASSLIB,AVIDLIB/UN=403180N
REWIND,*.
GET,RAUSYS/UN=727850N
SETCORE,ZERO
GET,NMACFTN/UN=LIBRARY
LIBRARY,NMACFTN
ATTACH,LIBFTEK/UN=LIBRARY
GET,RFANALB
FTN,I=RFANALB,L=T
LDSET,LIB=LASSLIB/FORTRAN/AVIDLIB/RAUSYS/LIBFTEK,PRESETA=0
LGO
REWIND,DAY
DAYFILE,DAY
REPLACE,DAY
EXIT
REWIND,DAY
DAYFILE,DAY
REPLACE,DAY
REVERT,RREX
 EOI ENCOUNTERED
/
```

```
 COPY,OIPROC
 PROC,RREX
MAP,OFF
GET,LASSLIB,AVIDLIB/UN=403180N.
REWIND,*
GET,RAUSYS/UN=727850N
SETCORE,ZERO
GET,NMACFTN/UN=LIBRARY.
LIBRARY,NMACFTN
ATTACH,LIBFTEK/UN=LIBRARY
GET,TRANSS
FTN,I=TRANSS,L=T
LDSET,LIB=LASSLIB/FORTRAN/AVIDLIB/RAUSYS/LIBFTEK,PRESETA=0
LGO
REWIND,DAY
DAYFILE,DAY
REPLACE,DAY
EXIT
REWIND,DAY
DAYFILE,DAY
REPLACE,DAY
REVERT,RREX
 EOI ENCOUNTERED
```

END OF PROCEDURE FILES

START OF LISTING OF GYASSA

GRID	10	0	0000	0	0000	7	0000	123456
GRID	101	0	0000	60	0000	14	0000	456
GRID	102	13	3513	58	4957	14	0000	456
GRID	103	26	0330	54	0581	14	0000	456
GRID	104	37	4094	46	9099	14	0000	456
GRID	105	46	9099	37	4094	14	0000	456
GRID	106	54	0581	26	0330	14	0000	456
GRID	107	58	4957	13	3513	14	0000	456
GRID	108	60	0000		0000	14	0000	456
GRID	109	58	4957	-13	3513	14	0000	456
GRID	110	54	0581	-26	0330	14	0000	456
GRID	111	46	9099	-37	4094	14	0000	456
GRID	112	37	4094	-46	9099	14	0000	456
GRID	113	26	0330	-54	0581	14	0000	456
GRID	114	13	3513	-58	4957	14	0000	456
GRID	115		0000	-60	0000	14	0000	456
GRID	116	-13	3513	-58	4957	14	0000	456
GRID	117	-26	0330	-54	0581	14	0000	456
GRID	118	-37	4094	-46	9099	14	0000	456
GRID	119	-46	9099	-37	4094	14	0000	456
GRID	120	-54	0581	-26	0330	14	0000	456
GRID	121	-58	4957	-13	3513	14	0000	456
GRID	122	-60	0000	-	0000	14	0000	456
GRID	123	-58	4957	13	3513	14	0000	456
GRID	124	-54	0581	26	0330	14	0000	456
GRID	125	-46	9099	37	4094	14	0000	456
GRID	126	-37	4094	46	9099	14	0000	456
GRID	127	-26	0330	54	0581	14	0000	456
GRID	128	-13	3513	58	4957	14	0000	456
GRID	201	0	0000	60	0000	0	0000	456
GRID	202	13	3513	58	4957	0	0000	456
GRID	203	26	0330	54	0581	0	0000	456
GRID	204	37	4094	46	9099	0	0000	456
GRID	205	46	9099	37	4094	0	0000	456
GRID	206	54	0581	26	0330	0	0000	456
GRID	207	58	4957	13	3513	0	0000	456
GRID	208	60	0000		0000	0	0000	456
GRID	209	58	4957	-13	3513	0	0000	456
GRID	210	54	0581	-26	0330	0	0000	456
GRID	211	46	9099	-37	4094	0	0000	456
GRID	212	37	4094	-46	9099	0	0000	456
GRID	213	26	0330	-54	0581	0	0000	456
GRID	214	13	3513	-58	4957	0	0000	456
GRID	215		0000	-60	0000	0	0000	456
GRID	216	-13	3513	-58	4957	0	0000	456
GRID	217	-26	0330	-54	0581	0	0000	456
GRID	218	-37	4094	-46	9099	0	0000	456
GRID	219	-46	9099	-37	4094	0	0000	456
GRID	220	-54	0581	-26	0330	0	0000	456

GRID	221	-58 4957	-13 3513	0 0000	456
GRID	222	-60 0000	- 0000	0 0000	456
GRID	223	-58.4957	13 3513	0.0000	456
GRID	224	-54 0581	26 0330	0 0000	456
GRID	225	-46 9099	37 4094	0 0000	456
GRID	226	-37.4094	46 9099	0 0000	456
GRID	227	-26 0330	54 0581	0 0000	456
GRID	228	-13 3513	58 4957	0 0000	456
GRID	301	0 0000	51 5000	0 0000	456
GRID	302	11 4598	50 2088	0.0000	456
GRID	303	22 3450	46 3999	0 0000	456
GRID	304	32 1097	40 2643	0.0000	456
GRID	305	40 2643	32 1097	0 0000	456
GRID	306	46 3999	22 3450	0 0000	456
GRID	307	50 2088	11 4598	0.0000	456
GRID	308	51.5000	0000	0 0000	456
GRID	309	50 2088	-11 4598	0 0000	456
GRID	310	46.3999	-22 3450	0 0000	456
GRID	311	40 2643	-32 1097	0 0000	456
GRID	312	32 1097	-40 2643	0.0000	456
GRID	313	22 3450	-46 3999	0.0000	456
GRID	314	11 4598	-50 2088	0 0000	456
GRID	315	0000	-51 5000	0 0000	456
GRID	316	-11 4598	-50 2088	0 0000	456
GRID	317	-22 3450	-46 3999	0 0000	456
GRID	318	-32 1097	-40 2643	0 0000	456
GRID	319	-40 2643	-32 1097	0.0000	456
GRID	320	-46 3999	-22 3450	0 0000	456
GRID	321	-50 2088	-11 4598	0 0000	456
GRID	322	-51 5000	- 0000	0 0000	456
GRID	323	-50 2088	11 4598	0 0000	456
GRID	324	-46 3999	22 3450	0 0000	456
GRID	325	-40 2643	32 1097	0 0000	456
GRID	326	-32 1097	40 2643	0 0000	456
GRID	327	-22 3450	46 3999	0 0000	456
GRID	328	-11 4598	50 2088	0 0000	456
GRID	401	0 0000	51 5000	14 0000	456
GRID	402	11 4598	50 2088	14 0000	456
GRID	403	22 3450	46 3999	14 0000	456
GRID	404	32 1097	40 2643	14 0000	456
GRID	405	40 2643	32 1097	14 0000	456
GRID	406	46 3999	22 3450	14 0000	456
GRID	407	50 2088	11 4598	14 0000	456
GRID	408	51 5000	0000	14 0000	456
GRID	409	50 2088	-11 4598	14 0000	456
GRID	410	46 3999	-22 3450	14 0000	456
GRID	411	40 2643	-32 1097	14 0000	456
GRID	412	32 1097	-40 2643	14 0000	456
GRID	413	22 3450	-46 3999	14 0000	456

```
GRID         414          11 4598 50 2088 14 0000           456
GRID         415             0000-51 5000 14 0000           456
GRID         416         -11 4598-50 2088 14 0000           456
GRID         417         -22 3450-46 3999 14 0000           456
GRID         418         -32 1097-40 2643 14 0000           456
GRID         419         -40 2643-32 1097 14 0000           456
GRID         420         -46 3999-22 3450 14 0000           456
GRID         421         -50 2088-11 4598 14 0000           456
GRID         422         -51 5000  -  0000 14 0000          456
GRID         423         -50 2088 11 4598 14 0000           456
GRID         424         -46 3999 22 3450 14 0000           456
GRID         425         -40 2643 32 1097 14 0000           456
GRID         426         -32 1097 40 2643 14 0000           456
GRID         427         -22 3450 46 3999 14 0000           456
GRID         428         -11 4598 50 2088 14 0000           456
PROD         100      500 146E-03 377E-06 0        0
MAT1         5001 38E+112 06E+100          1939 30          0
+BC      0        0        0
PROD         150      501 128E-03 252E-06 0        0
MAT1            5011 38E+112 06E+100          1939 S05        0
+BC      0        0        0
PROD         200      502 109E-03 159E-06 0        0
MAT1         5021 38E+112 06E+100          1939 30          0
+BC      0        0        0
PROD         300      503 251E-03 299E-06 0        0
MAT1         5031 38E+112 06E+100          1939 30          0
+BC      0        0        0
PROD         400      504 233E-04 0       0        0
MAT1         5041 38E+112 06E+100          1939 30          0
+BC      0        0        0
CROD         101    100       101       102
CROD         102    100       201       202
CROD         103    150       301       302
CROD         104    150       401       402
CROD         105    200       101       401
CROD         106    200       201       301
CROD         107    300       101       201
CROD         108    300       401       301
CROD         109    400       101       301
CROD         110    400       201       401
CROD         111    400       101       202
CROD         112    400       201       102
CROD         113    400       201       302
CROD         114    400       301       202
CROD         115    400       301       402
CROD         116    400       401       302
CROD         117    400       401       102
CROD         118    400       101       402
CROD         201    100       102       103
```

CROD	202	100	202	203
CROD	203	150	302	303
CROD	204	150	402	403
CROD	205	200	102	402
CROD	206	200	202	302
CROD	207	300	102	202
CROD	208	300	402	302
CROD	209	400	102	302
CROD	210	400	202	402
CROD	211	400	102	203
CROD	212	400	202	103
CROD	213	400	202	303
CROD	214	400	302	203
CROD	215	400	302	403
CROD	216	400	402	303
CROD	217	400	402	103
CROD	218	400	102	403
CROD	301	100	103	104
CROD	302	100	203	204
CROD	303	150	303	304
CROD	304	150	403	404
CROD	305	200	103	403
CROD	306	200	203	303
CROD	307	300	103	203
CROD	308	300	403	303
CROD	309	400	103	303
CROD	310	400	203	403
CROD	311	400	103	204
CROD	312	400	203	104
CROD	313	400	203	304
CROD	314	400	303	204
CROD	315	400	303	404
CROD	316	400	403	304
CROD	317	400	403	104
CROD	318	400	103	404
CROD	401	100	104	105
CROD	402	100	204	205
CROD	403	150	304	305
CROD	404	150	404	405
CROD	405	200	104	404
CROD	406	200	204	304
CROD	407	300	104	204
CROD	408	300	404	304
CROD	409	400	104	304
CROD	410	400	204	404
CROD	411	400	104	205
CROD	412	400	204	105
CROD	413	400	204	305
CROD	414	400	304	205
CROD	415	400	304	405
CROD	416	400	404	305
CROD	417	400	404	105
CROD	418	400	104	405

CROD	501	100	105	106
CROD	502	100	205	206
CROD	503	150	305	306
CROD	504	150	405	406
CROD	505	200	105	405
CROD	506	200	205	305
CROD	507	300	105	205
CROD	508	300	405	305
CROD	509	400	105	305
CROD	510	400	205	405
CROD	511	400	105	206
CROD	512	400	205	106
CROD	513	400	205	306
CROD	514	400	305	206
CROD	515	400	305	406
CROD	516	400	405	306
CROD	517	400	405	106
CROD	518	400	105	406
CROD	601	100	106	107
CROD	602	100	206	207
CROD	603	150	306	307
CROD	604	150	406	407
CROD	605	200	106	406
CROD	606	200	206	306
CROD	607	300	106	206
CROD	608	300	406	306
CROD	609	400	106	306
CROD	610	400	206	406
CROD	611	400	106	207
CROD	612	400	206	107
CROD	613	400	206	307
CROD	614	400	306	207
CROD	615	400	306	407
CROD	616	400	406	307
CROD	617	400	406	107
CROD	618	400	106	407
CROD	701	100	107	108
CROD	702	100	207	208
CROD	703	150	307	308
CROD	704	150	407	408
CROD	705	200	107	407
CROD	706	200	207	307
CROD	707	300	107	207
CROD	708	300	407	307
CROD	709	400	107	307
CROD	710	400	207	407
CROD	711	400	107	208
CROD	712	400	207	108
CROD	713	400	207	308

CROD	714	400	307	208
CROD	715	400	307	408
CROD	716	400	407	308
CROD	717	400	407	108
CROD	718	400	107	408
CROD	801	100	108	109
CROD	802	100	208	209
CROD	803	150	308	309
CROD	804	150	408	409
CROD	805	200	108	408
CROD	806	200	208	308
CROD	807	300	108	208
CROD	808	300	408	308
CROD	809	400	108	308
CROD	810	400	208	408
CROD	811	400	108	209
CROD	812	400	208	109
CROD	813	400	208	309
CROD	814	400	308	209
CROD	815	400	308	409
CROD	816	400	408	309
CROD	817	400	408	109
CROD	818	400	108	409
CROD	901	100	109	110
CROD	902	100	209	210
CROD	903	150	309	310
CROD	904	150	409	410
CROD	905	200	109	409
CROD	906	200	209	309
CROD	907	300	109	209
CROD	908	300	409	309
CROD	909	400	109	309
CROD	910	400	209	409
CROD	911	400	109	210
CROD	912	400	209	110
CROD	913	400	209	310
CROD	914	400	309	210
CROD	915	400	309	410
CROD	916	400	409	310
CROD	917	400	409	110
CROD	918	400	109	410
CROD	1001	100	110	111
CROD	1002	100	210	211
CROD	1003	150	310	311
CROD	1004	150	410	411
CROD	1005	200	110	410
CROD	1006	200	210	310
CROD	1007	300	110	210
CROD	1008	300	410	310

CROD	1009	400	110	310
CROD	1010	400	210	410
CROD	1011	400	110	211
CROD	1012	400	210	111
CROD	1013	400	210	311
CROD	1014	400	310	211
CROD	1015	400	310	411
CROD	1016	400	410	311
CROD	1017	400	410	111
CROD	1018	400	110	411
CROD	1101	100	111	112
CROD	1102	100	211	212
CROD	1103	150	311	312
CROD	1104	150	411	412
CROD	1105	200	111	411
CROD	1106	200	211	311
CROD	1107	300	111	211
CROD	1108	300	411	311
CROD	1109	400	111	311
CROD	1110	400	211	411
CROD	1111	400	111	212
CROD	1112	400	211	112
CROD	1113	400	211	312
CROD	1114	400	311	212
CROD	1115	400	311	412
CROD	1116	400	411	312
CROD	1117	400	411	112
CROD	1118	400	111	412
CROD	1201	100	112	113
CROD	1202	100	212	213
CROD	1203	150	312	313
CROD	1204	150	412	413
CROD	1205	200	112	412
CROD	1206	200	212	312
CROD	1207	300	112	212
CROD	1208	300	412	312
CROD	1209	400	112	312
CROD	1210	400	212	412
CROD	1211	400	112	213
CROD	1212	400	212	113
CROD	1213	400	212	313
CROD	1214	400	312	213
CROD	1215	400	312	413
CROD	1216	400	412	313
CROD	1217	400	412	113
CROD	1218	400	112	413
CROD	1301	100	113	114
CROD	1302	100	213	214
CROD	1303	150	313	314

CROD	1304	150	413	414
CROD	1305	200	113	413
CROD	1306	200	213	313
CROD	1307	300	113	213
CROD	1308	300	413	313
CROD	1309	400	113	313
CROD	1310	400	213	413
CROD	1311	400	113	214
CROD	1312	400	213	114
CROD	1313	400	213	314
CROD	1314	400	313	214
CROD	1315	400	313	414
CROD	1316	400	413	314
CROD	1317	400	413	114
CROD	1318	400	113	414
CROD	1401	100	114	115
CROD	1402	100	214	215
CROD	1403	150	314	315
CROD	1404	150	414	415
CROD	1405	200	114	414
CROD	1406	200	214	314
CROD	1407	300	114	214
CROD	1408	300	414	314
CROD	1409	400	114	314
CROD	1410	400	214	414
CROD	1411	400	114	215
CROD	1412	400	214	115
CROD	1413	400	214	315
CROD	1414	400	314	215
CROD	1415	400	314	415
CROD	1416	400	414	315
CROD	1417	400	414	115
CROD	1418	400	114	415
CROD	1501	100	115	116
CROD	1502	100	215	216
CROD	1503	150	315	316
CROD	1504	150	415	416
CROD	1505	200	115	415
CROD	1506	200	215	315
CROD	1507	300	115	215
CROD	1508	300	415	315
CROD	1509	400	115	315
CROD	1510	400	215	415
CROD	1511	400	115	216
CROD	1512	400	215	116
CROD	1513	400	215	316
CROD	1514	400	315	216
CROD	1515	400	315	416
CROD	1516	400	415	316

CROD	1517	400	415	116
CROD	1518	400	115	416
CROD	1601	100	116	117
CROD	1602	100	216	217
CROD	1603	150	316	317
CROD	1604	150	416	417
CROD	1605	200	116	416
CROD	162@	200	216	316
CROD	1607	300	116	216
CROD	1608	300	416	316
CROD	1609	400	116	316
CROD	1610	400	216	416
CROD	1611	400	116	217
CROD	1612	400	216	117
CROD	1613	400	216	317
CROD	1614	400	316	217
CROD	1615	400	316	417
CROD	1616	400	416	317
CROD	1617	400	416	117
CROD	1618	400	116	417
CROD	1701	100	117	118
CROD	1702	100	217	218
CROD	1703	150	317	318
CROD	1704	150	417	418
CROD	1705	200	117	417
CROD	1706	200	217	317
CROD	1707	300	117	217
CROD	1708	300	417	317
CROD	1709	400	117	317
CROD	1710	400	217	417
CROD	1711	400	117	218
CROD	1712	400	217	118
CROD	1713	400	217	318
CROD	1714	400	317	218
CROD	1715	400	317	418
CROD	1716	400	417	318
CROD	1717	400	417	118
CROD	1718	400	117	418
CROD	1801	100	118	119
CROD	1802	100	218	219
CROD	1803	150	318	319
CROD	1804	150	418	419
CROD	1805	200	118	418
CROD	1806	200	218	318
CROD	1807	300	118	218
CROD	1808	300	418	318
CROD	1809	400	118	318
CROD	1810	400	218	418
CROD	1811	400	118	219

CROD	1812	400	218	119
CROD	1813	400	218	319
CROD	1814	400	318	219
CROD	1815	400	318	419
CROD	1816	400	418	319
CROD	1817	400	418	119
CROD	1818	400	118	419
CROD	1901	100	119	120
CROD	1902	100	219	220
CROD	1903	150	319	320
CROD	1904	150	419	420
CROD	1905	200	119	419
CROD	1906	200	219	319
CROD	1907	300	119	219
CROD	1908	300	419	319
CROD	1909	400	119	319
CROD	1910	400	219	419
CROD	1911	400	119	220
CROD	1912	400	219	120
CROD	1913	400	219	320
CROD	1914	400	319	220
CROD	1915	400	319	420
CROD	1916	400	419	320
CROD	1917	400	419	120
CROD	1918	400	119	420
CROD	2001	100	120	121
CROD	2002	100	220	221
CROD	2003	150	320	321
CROD	2004	150	420	421
CROD	2005	200	120	420
CROD	2006	200	220	320
CROD	2007	300	120	220
CROD	2008	300	420	320
CROD	2009	400	120	320
CROD	2010	400	220	420
CROD	2011	400	120	221
CROD	2012	400	220	121
CROD	2013	400	220	321
CROD	2014	400	320	221
CROD	2015	400	320	421
CROD	2016	400	420	321
CROD	2017	400	420	121
CROD	2018	400	120	421
CROD	2101	100	121	122
CROD	2102	100	221	222
CROD	2103	150	321	322
CROD	2104	150	421	422
CROD	2105	200	121	421
CROD	2106	200	221	321

CROD	2107	300	121	221
CROD	2108	300	421	321
CROD	2109	400	121	321
CROD	2110	400	221	421
CROD	2111	400	121	222
CROD	2112	400	221	122
CROD	2113	400	221	322
CROD	2114	400	321	222
CROD	2115	400	321	422
CROD	2116	400	421	322
CROD	2117	400	421	122
CROD	2118	400	121	422
CROD	2201	100	122	123
CROD	2202	100	222	223
CROD	2203	150	322	323
CROD	2204	150	422	423
CROD	2205	200	122	422
CROD	2206	200	222	322
CROD	2207	300	122	222
CROD	2208	300	422	322
CROD	2209	400	122	322
CROD	2210	400	222	422
CROD	2211	400	122	223
CROD	2212	400	222	123
CROD	2213	400	222	323
CROD	2214	400	322	223
CROD	2215	400	322	423
CROD	2216	400	422	323
CROD	2217	400	422	123
CROD	2218	400	122	423
CROD	2301	100	123	124
CROD	2302	100	223	224
CROD	2303	150	323	324
CROD	2304	150	423	424
CROD	2305	200	123	423
CROD	2306	200	223	323
CROD	2307	300	123	223
CROD	2308	300	423	323
CROD	2309	400	123	323
CROD	2310	400	223	423
CROD	2311	400	123	224
CROD	2312	400	223	124
CROD	2313	400	223	324
CROD	2314	400	323	224
CROD	2315	400	323	424
CROD	2316	400	423	324
CROD	2317	400	423	124
CROD	318	400	123	424
CROD	2401	100	124	125

CROD	2402	100	224	225
CROD	2403	150	324	325
CROD	2404	150	424	425
CROD	2405	200	124	424
CROD	2406	200	224	324
CROD	2407	300	124	224
CROD	2408	300	424	324
CROD	2409	400	124	324
CROD	2410	400	224	424
CROD	2411	400	124	225
CROD	2412	400	224	125
CROD	2413	400	224	325
CROD	2414	400	324	225
CROD	2415	400	324	425
CROD	2416	400	424	325
CROD	2417	400	424	125
CROD	2418	400	124	425
CROD	2501	100	125	126
CROD	2502	100	225	226
CROD	2503	150	325	326
CROD	2504	150	425	426
CROD	2505	200	125	425
CROD	2506	200	225	325
CROD	2507	300	125	225
CROD	2508	300	425	325
CROD	2509	400	125	325
CROD	2510	400	225	425
CROD	2511	400	125	226
CROD	2512	400	225	126
CROD	2513	400	225	326
CROD	2514	400	325	226
CROD	2515	400	325	426
CROD	2516	400	425	326
CROD	2517	400	425	126
CROD	2518	400	125	426
CROD	2601	100	126	127
CROD	2602	100	226	227
CROD	2603	150	326	327
CROD	2604	150	426	427
CROD	2605	200	126	426
CROD	2606	200	226	326
CROD	2607	300	126	226
CROD	2608	300	426	326
CROD	2609	400	126	326
CROD	2610	400	226	426
CROD	2611	400	126	227
CROD	2612	400	226	127
CROD	2613	400	226	327
CROD	2614	400	QH326	227

CROD	2615	400	326	427	
CROD	2616	400	426	327	
CROD	2617	400	426	127	
CROD	2618	400	126	427	
CROD	2701	100	127	128	
CROD	2702	100	227	228	
CROD	2703	150	327	328	
CROD	2704	150	427	428	
CROD	2705	200	127	427	
CROD	2706	200	227	327	
CROD	2707	300	127	227	
CROD	2708	300	427	327	
CROD	2709	400	127	327	
CROD	2710	400	227	427	
CROD	2711	400	127	228	
CROD	2712	400	227	128	
CROD	2713	400	227	328	
CROD	2714	400	327	228	
CROD	2715	400	327	428	
CROD	2716	400	427	328	
CROD	2717	400	427	128	
CROD	2718	400	127	428	
CROD	2801	100	128	101	
CROD	2802	100	228	201	
CROD	2803	150	328	301	
CROD	2804	150	428	401	
CROD	2805	200	128	t2#	
CROD	2806	200	228	328	
CROD	2807	300	128	d8	
CROD	2808	300	428	328	
CROD	2809	400	128	328	
CROD	2810	400	228	428	
CROD	2811	400	128	201	
CROD	2812	400	228	101	
CROD	2813	400	228	301	
CROD	2814	400	328	201	
CROD	2815	400	328	401	
CROD	2816	400	428	301	
CROD	2817	400	428	101	
CROD	2818	400	128	401	
CONM2	102	102		340	908
CONM2	103	103			908
CONM2	104	104			908
CONM2	105	105		15	908
CONM2	106	106			908
CONM2	107	107			908
CONM2	108	108		459	408
CONM2	109	109			908
CONM2	110	110			908

CONM2	111	111	15	908
CONM2	112	112		908
CONM2	113	113		908
CONM2	114	114	340	908
CONM2	116	116	340	908
CONM2	117	117		908
CONM2	118	118		908
CONM2	119	119	15	908
CONM2	120	120		908
CONM2	121	121		908
CONM2	122	122	459	000
CONM2	123	123		908
CONM2	124	124		908
CONM2	125	125	15	908
CONM2	126	126		908
CONM2	127	127		908
CONM2	128	128	340	908
CONM2	201	201		908
CONM2	202	202		908
CONM2	203	203		908
CONM2	204	204		908
CONM2	205	205		908
CONM2	206	206		908
CONM2	207	207		908
CONM2	208	208		908
CONM2	209	209		908
CONM2	210	210		908
CONM2	211	211		908
CONM2	212	212		908
CONM2	213	213		908
CONM2	214	214		908
CONM2	215	215		908
CONM2	216	216		908
CONM2	217	217		908
CONM2	218	218		908
CONM2	219	219		908
CONM2	220	220		908
CONM2	221	221		908
CONM2	222	222		908
CONM2	223	223		908
CONM2	224	224		908
CONM2	225	225		908
CONM2	226	226		908
CONM2	227	227		908
CONM2	228	228		908
CONM2	301	301	15	450
CONM2	302	302	15	450
CONM2	303	303	15	450
CONM2	304	304	15	450

CONM2	305	305	15	450
CONM2	306	306	15	450
CONM2	307	307	15	450
CONM2	308	308	15	450
CONM2	309	309	15	450
CONM2	310	310	15	450
CONM2	311	311	15	450
CONM2	312	312	15	450
CONM2	313	313	15	450
CONM2	314	314	15	450
CONM2	315	315	15	450
CONM2	316	316	15	450
CONM2	317	317	15	450
CONM2	318	318	15	450
CONM2	319	319	15	450
CONM2	320	320	15	450
CONM2	321	321	15	450
CONM2	322	322	15	450
CONM2	323	323	15	450
CONM2	324	324	15	450
CONM2	325	325	15	450
CONM2	326	326	15	450
CONM2	327	327	15	450
CONM2	328	328	15	450
CONM2	401	401	15	450
CONM2	402	402	15	450
CONM2	403	403	15	450
CONM2	404	404	15	450
CONM2	405	405	15	450
CONM2	406	406	15	450
CONM2	407	407	15	450
CONM2	408	408	15	450
CONM2	409	409	15	450
CONM2	410	410	15	450
CONM2	411	411	15	450
CONM2	412	412	15	450
CONM2	413	413	15	450
CONM2	414	414	15	450
CONM2	415	415	15	450
CONM2	416	416	15	450
CONM2	417	417	15	450
CONM2	418	418	15	450
CONM2	419	419	15	450
CONM2	420	420	15	450
CONM2	421	421	15	450
CONM2	422	422	15	450
CONM2	423	423	q	450
CONM2	424	424	15	450
CONM2	$`725	425	15	450

CONM2	426	426			15	450		
CONM2	427	427			15	450		
CONM2	428	428			15	450		
FORCE1	301	301	45	410		301	10	
FORCE1	302	302	45	410		302	10	
FORCE1	303	303	45	410		303	10	
FORCE1	304	304	45	410		304	10	
FORCE1	305	305	45	410		305	10	
FORCE1	306	306	45.	410		306	10	
FORCE1	307	307	45	410		307	10	
FORCE1	308	308	45	410		308	10	
FORCE1	309	309	45	410		309	10	
FORCE1	310	310	45	410		310	10	
FORCE1	311	311	45	410		311	10	
FORCE1	312	312	45	410		312	10	
FORCE1	313	313	45	410		313	10	
FORCE1	314	314	45	410		314	10	
FORCE1	315	315	45	410		315	10	
FORCE1	316	316	45	410		316	q0	
								FOR
FORCE1	318	318	45	410		318	10	
FORCE1	319	319	45	410		319	10	
FORCE1	320	320	45	410		320	10	
FORCE1	321	321	45	410		321	10	
FORCE1	322	322	45	410		322	10	
FORCE1	323	323	45	410		323	10	
FORCE1	324	324	45	410		324	10	
FORCE1	325	325	45	410		325	10	
FORCE1	326	326	45	410		326	10	
FORCE1	327	327	45	410		327	10	
FORCE1	328	328	45	410		328	10	
FORCE1	401	401	45	410		401	10	
FORCE1	402	402	45	410		402	10	
FORCE1	403	403	45	410		403	10	
FORCE1	404	404	45	410		404	10	
FORCE1	405	405	45	410		405	10	
FORCE1	406	406	45	410		406	10	
FORCE1	407	407	45	410		407	10	
FORCE1	408	408	45	410		408	10	
FORCE1	409	409	45	410		409	10	
FORCE1	410	410	45	410		410	10	
FORCE1	411	411	45	410		411	10	
FORCE1	412	412	45	410		412	10	
FORCE1	413	413	45	410		413	10	
FORCE1	414	414	45	410		414	10	
FORCE1	415	415	45	410		415	10	
FORCE1	416	416	45	410		416	10	
FORCE1	417	417	45	410		417	10	
FORCE1	418	418	45	410		418	10	

```
FORCE1       419        419    45  410        419         10
FORCE1       420        420    45  410        420         10
FORCE1       421        421    45  410        421         10
FORCE1       422        422    45  410        422         10
FORCE1       423        423    45  410        423         10
FORCE1       424        424    45  410        424         10
FORCE1       425        425    45  410        425         10
FORCE1       426        426    45  410        426         10
FORCE1       427        427    45  410        427         10
FORCE1       428        428    45  410        428         10
GRID         429                0  000   11  500  100  000           456
GRID         430                0  000  -11  500  100  000           456
PROD         401        505   59E-04   74E-05
PROD         402        506   16E-04   80E-06
PROD         403        507   59E-04   74E-05
MAT1         505   13E+12     12E+11               4980  00
MAT1         506   13E+12     12E+11               1939  00
MAT1         507   13E+12     12E+11               4980  00
CROD        2819        401      101        429
CROD        2820        402      429        430
CROD        2821        403      430        115
CONM2        101        101              15  976
CONM2        115        115              15  976
CONM2        429        429             376  000
CONM2        430        430             376  000
ENDDATA
  -EOR--

                       END OF  DYASSA
```

START OF LISTING OF DYRIBH

```
BEGIN BULK
$  DATA FOR RADIAL RIB CONFIGURATION
$  INCLUDING CIRCUMFERENITAL HOOP
$  INCLUDING CENTRAL FEED MAST
$  INCLUDING FEED SUPPORT STAYS
$    NO  OF RIBS, DIAMETER, FOCAL LENGTH/DIA =    24  100 00     1 00
GRID          10              0 00     0 00     0 00
GRID          11              0 00     0 00   100 00
$  GRID, BAR ELEMENTS, MESH MASS FOR RIB  1
GRID          101             0 00     8 33       17
GRID          102             0 00    16 67       69
GRID          103             0 00    25 00     1 56
GRID          104             0 00    33 33     2 78
GRID          105             0 00    41 67     4 34
GRID          106             0 00    50 00     6 25
CBAR          101     101       10      101       11                    2
CBAR          102     102      101      102       11                    2
CBAR          103     103      102      103       11                    2
CBAR          104     104      103      104       11                    2
CBAR          105     105      104      105       11                    2
CBAR          106     106      105      106       11                    2
CONM2         101     101              1 821
CONM2         102     102              3 651
CONM2         103     103              5.500
CONM2         104     104              7 377
CONM2         105     105              9 291
CONM2         106     106              5 129
$  GRID, BAR ELEMENTS, MESH MASS FOR RIB  2
GRID          201             2 16     8 05       17
GRID          202             4 31    16 10       69
GRID          203             6 47    24 15     1 56
GRID          204             8 63    32 20     2 78
GRID          205            10 78    40 25     4 34
GRID          206            12 94    48 30     6 25
CBAR          201     101       10      201       11                    2
CBAR          202     102      201      202       11                    2
CBAR          203     103      202      203       11                    2
CBAR          204     104      203      204       11                    2
CBAR          205     105      204      205       11                    2
CBAR          206     106      205      206       11                    2
CONM2         201     201              1 821
CONM2         202     202              3 651
CONM2         203     203              5 500
CONM2         204     204              7 377
CONM2         205     205              9 291
CONM2         206     206              5 129
$  GRID, BAR ELEMENTS, MESH MASS FOR RIB  3
GRID          301             4 17     7 22       17
GRID          302             8 33    14 43       69
GRID          303            12 50    21 65     1 56
GRID          304            16 67    28 87     2 78
GRID          305            20 83    36 08     4 34
GRID          306            25 00    43 30     6 25
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CBAR        301      101       10      301       11              2
CBAR        302      102      301      302       11              2
CBAR        303      103      302      303       11              2
CBAR        304      104      303      304       11              2
CBAR        305      105      304      305       11              2
CBAR        306      106      305      306       11              2
CONM2       301      301             1 821
CONM2       302      302             3 651
CONM2       303      303             5 500
CONM2       304      304             7 377
CONM2       305      305             9 291
CONM2       306      306             5 129

              CONTINUE FOR RIBS 4 THROUGH 23

$  GRID, BAR ELEMENTS, MESH MASS FOR RIB 24
GRID       2401             -2 16     8 05       17
GRID       2402             -4 31    16 10       69
GRID       2403             -6 47    24 15     1 56
GRID       2404             -8 63    32 20     2 78
GRID       2405            -10 78    40 25     4 34
GRID       2406            -12 94    48 30     6 25
CBAR       2401      101       10     2401       11              2
CBAR       2402      102     2401     2402       11              2
CBAR       2403      103     2402     2403       11              2
CBAR       2404      104     2403     2404       11              2
CBAR       2405      105     2404     2405       11             2
CBAR       2406      106     2405     2406       11              2
CONM2      2401     2401              1 821
CONM2      2402     2402              3 651
CONM2      2403     2403              5 500
CONM2      2404     2404              7 77
CONM2      2405     2405              9 291
CONM2      2406     2406              5 129
$  CONCENTRATED MASS FOR HUB
CONM2        10       10           473 911
$  RIB PROPERTIES, MATERIALS
PBAR        101       1004 92E-047 01E-064 94E-061 20E-05
PBAR        102       1004 75E-046 83E-064 23E-061 11E-05
PBAR        103       1004 58E-046 64E-063 51E-061 02E-05
PBAR        104       1004 42E-046 46E-062 79E-069 27E-06
PBAR        105       1004 25E-046 28E-062 08E-068 38E-06
PBAR        106       1004 08E-046 09E-061 36E-067 49E-06
MAT1        1007 00E+101 00E+10          1 94E+03
```

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$ HOOP GRID, ELEMENTS, PROPERITES AND MATERIALS
GRID           5              0 00     0 00     6 25            123456
GRID         150              6 53    49 57     6 25
CBAR      100001      200      106      150        5                    2
CBAR      100002      200      150      206        5                    2
GRID         250             19 13    46 19     6 25
CBAR      100003      200      206      250        5                    2
CBAR      100004      200      250      306        5                    2
GRID         350             30 44    39 67     6 25
CBAR      100005      200      306      350        5                    2
CBAR      100006      200      350      406        5                    2
GRID         450             39 67    30 44     6 25
CBAR      100007      200      406      450        5                    2
CBAR      100008      200      450      506        5                    2
GRID         550             46 19    19 13     6 25
CBAR      100009      200      506      550        5                    2
CBAR      100010      200      550      606        5                    2
GRID         650             49 57     6 53     6 25
CBAR      100011      200      606      650        5                    2
CBAR      100012      200      650      706        5                    2
GRID         750             49 57    -6 53     6 25
CBAR      100013      200      706      750        5                    2
CBAR      100014      200      750      806        5                    2
GRID         850             46 19   -19 13     6 25
CBAR      100015      200      806      850        5                    2
CBAR      100016      200      850      906        5                    2
GRID         950             39 67   -30 44     6 25
CBAR      100017      200      906      950        5                    2
CBAR      100018      200      950     1006        5                    2
GRID        1050             30 44   -39 67     6 25
CBAR      100019      200     1006     1050        5                    2
CBAR      100020      200     1050     1106        5                    2
GRID        1150             19 13   -46 19     6 25
CBAR      100021      200     1106     1150        5                    2
CBAR      100022      200     1150     1206        5                    2
GRID        1250              6 53   -49 57     6 25
CBAR      100023      200     1206     1250        5                    2
CBAR      100024      200     1250     1306        5                    2
GRID        1350             -6 53   -49 57     6 25
CBAR      100025      200     1306     1350        5                    2
CBAR      100026      200     1350     1406        5                    2
GRID        1450            -19 13   -46 19     6 25
CBAR      100027      200     1406     1450        5                    2
CBAR      100028      200     1450     1506        5                    2
GRID        1550            -30 44   -39 67     6 25
CBAR      100029      200     1506     1550        5                    2
CBAR      100030      200     1550     1606        5                    2
GRID        1650            -39 67   -30 44     6 25
CBAR      100031      200     1606     1650        5                    2
CBAR      100032      200     1650     1706        5                    2
GRID        1750            -46 19   -19 13     6 25
CBAR      100033      200     1706     1750        5                    2
CBAR      100034      200     1750     1806        5                    2
```

GRID	1850		-49 57	-6 53	6 25	
CBAR	100035	200	1806	1850	5	2
CBAR	100036	200	1850	1906	5	2
GRID	1950		-49 57	6 53	6 25	
CBAR	100037	200	1906	1950	5	2
CBAR	100038	200	1950	2006	5	2
GRID	2050		-46 19	19 13	6 25	
CBAR	100039	200	2006	2050	5	2
CBAR	100040	200	2050	2106	5	2
GRID	2150		-39 67	30 44	6 25	
CBAR	100041	200	2106	2150	5	2
CBAR	100042	200	2150	2206	5	2
GRID	2250		-30 44	39 67	6 25	
CBAR	100043	200	2206	2250	5	2
CBAR	100044	200	2250	2306	5	2
GRID	2350		-19 13	46 19	6 25	
CBAR	100045	200	2306	2350	5	

END OF DYRTIME

START OF DYCT

```
BEGIN BULK
$ TITLE = MPTEST
GRID     100000          0.00     0.00     2.23         123456
$ GRIDWORK
GRID        111111       0.000    0.000    0.000        123456
GRID        111112       4.457    0.000     .281        123456
GRID        211112      -4.457    0.000     .281        123456
GRID        111113       8.841    0.000    1.105        123456
GRID        211113      -8.841    0.000    1.105        123456
GRID        111211       0.000    4.457     .281        123456
GRID        211211       0.000   -4.457     .281        123456
GRID        111212       4.457    4.457     .562        123456
GRID        211212      -4.457    4.457     .562        123456
GRID        311212      -4.457   -4.457     .562        123456
GRID        411212       4.457   -4.457     .562        123456
GRID        111213       8.841    4.457    1.386        123456
GRID        211213      -8.841    4.457    1.386        123456
GRID        311213      -8.841   -4.457    1.386        123456
GRID        411213       8.841   -4.457    1.386        123456
GRID        111311       0.000    8.841    1.105        123456
GRID        211311       0.000   -8.841    1.105        123456
GRID        111312       4.457    8.841    1.386        123456
GRID        211312      -4.457    8.841    1.386        123456
GRID        311312      -4.457   -8.841    1.386        123456
GRID        411312       4.457   -8.841    1.386        123456
GRID        121111       0.000    0.000    8.840        123456
GRID        121112       4.457    0.000    9.121        123456
GRID        221112      -4.457    0.000    9.121        123456
GRID        121113       8.841    0.000    9.945        123456
GRID        221113      -8.841    0.000    9.945        123456
GRID        121211       0.000    4.457    9.121        123456
GRID        221211       0.000   -4.457    9.121        123456
GRID        121212       4.457    4.457    9.402        123456
GRID        221212      -4.457    4.457    9.402        123456
GRID        321212      -4.457   -4.457    9.402        123456
GRID        421212       4.457   -4.457    9.402        123456
GRID        121213       8.841    4.457   10.226        123456
GRID        221213      -8.841    4.457   10.226        123456
GRID        321213      -8.841   -4.457   10.226        123456
GRID        421213       8.841   -4.457   10.226        123456
GRID        121311       0.000    8.841    9.945        123456
GRID        221311       0.000   -8.841    9.945        123456
GRID        121312       4.457    8.841   10.226        123456
GRID        221312      -4.457    8.841   10.226        123456
GRID        321312      -4.457   -8.841   10.226        123456
GRID        421312       4.457   -8.841   10.226        123456
```

```
CBAR      110001   999911   111111   1111121 0      0 0      0 0
+110001    56       456
CBAR      110002   999911   111112   1111131 0      0 0      0 0
+110002    56       456
CBAR      110003   999911   111211   1112121 0      0 0      0 0
+110003    56       456
CBAR      110004   999911   111212   1112131 0      0 0      0 0
+110004    56       456
CBAR      110005   999911   111311   1113121 0      0 0      0 0
+110005    56       456
CBAR      110006   999911   111111   1112111 0      0 0      0 0
+110006    56       456
CBAR      110007   999911   111211   1113111 0      0 0      0 0
+110007    56       456
CBAR      110008   999911   111112   1112121 0      0 0      0 0
+110008    56       456
CBAR      110009   999911   111212   1113121 0      0 0      0 0
+110009    56       456
CBAR      110010   999911   111113   1112131 0      0 0      0 0
+110010    56       456
CBAR      110011   999911   111111   2111121 0      0 0      0 0
+110011   456        56
CBAR      110012   999911   211112   2111131.0      0.0      0.0
+110012   456        56
CBAR      110013   999911   111211   2112121 0      0 0      0.0
+110013   456        56
CBAR      110014   999911   211212   2112131 0      0 0      0 0
+110014   456        56
CBAR      110015   999911   111311   2113121 0      0.0      0 0
+110015   456        56
CBAR      110016   999911   211112   2112121 0      0 0      0 0
+110016   456        56
CBAR      110017   999911   211212   2113121 0      0 0      0.0
+110017   456        56
CBAR      110018   999911   211113   2112131 0      0 0      0 0
+110018   456        56
CBAR      110019   999911   211211   3112121 0      0.0      0 0
+110019   456        56
CBAR      110020   999911   311212   3112131 0      0 0      0 0
+110020   456        56
CBAR      110021   999911   211311   3113121 0      0.0      0 0
+110021   456        56
CBAR      110022   999911   111111   2112111 0      0 0      0 0
+110022   456        56
CBAR      110023   999911   211211   2113111 0      0 0      0 0
+110023   456        56
CBAR      110024   999911   211112   3112121 0      0 0      0 0
+110024   456        56
CBAR      110025   999911   311212   3113121 0      0 0      0 0
+110025   456        56
CBAR      110026   999911   211113   3112131 0      0 0      0.0
+110026   456        56
```

```
CBAR     110027  999911  211211  4112121 0       0 0     0 0
+110027   456     56
CBAR     110028  999911  411212  4112131 0       0 0     0 0
+110028   456     56
CBAR     110029  999911  211311  4113121 0       0 0     0 0
+110029   456     56
CBAR     110030  999911  111112  4112121 0       0 0     0 0
+110030  -456     56
CBAR     110031  999911  411212  4113121 0       0 0     0 0
+110031   456     56
CBAR     110032  999911  111113  4112131 0       0 0     0 0
+110032   456     56
CBAR     120001  999911  121111  1211121 0       0 0     0 0
+120001   56     456
CBAR     120002  999911  121112  1211131 0       0 0     0 0
+120002   56     456
CBAR     120003  999911  121211  1212121 0       0 0     0 0
+120003   56     456
CBAR     120004  999911  121212  1212131 0       0 0     0 0
+120004   56     456
CBAR     120005  999911  121311  1213121 0       0 0     0 0
+120005   56     456
CBAR     120006  999911  121111  1212111 0       0 0     0 0
+120006   56     456
CBAR     120007  999911  121211  1213111 0       0 0     0 0
+120007   56     456
CBAR     120008  999911  121112  1212121 0       0 0     0 0
+120008   56     456
CBAR     120009  999911  121212  1213121 0       0 0     0 0
+120009   56     456
CBAR     120010  999911  121113  1212131 0       0 0     0 0
+120010   56     456
CBAR     120011  999911  121111  2211121 0       0 0     0 0
+120011   456     56
CBAR     120012  999911  221112  2211131 0       0 0     0 0
+120012   456     56
CBAR     120013  999911  121211  2212121 0       0 0     0 0
+120013   456     56
CBAR     120014  999911  221212  2212131 0       0.0     0 0
+120014   456     56
CBAR     120015  999911  121311  2213121 0       0 0     0 0
+120015   456     56
CBAR     120016  999911  221112  2212121 0       0 0     0 0
+120016   456     56
CBAR     120017  999911  221212  2213121 0       0 0     0.0
+120017   456     56
CBAR     120018  999911  221113  2212131 0       0 0     0 0
+120018   456     56
CBAR     120019  999911  221211  3212121 0       0 0     0 0
+120019   456     56
CBAR     120020  999911  321212  3212131 0       0 0     0 0
+120020   456     56
```

```
CBAR     120021  999911  221311  3213121 0      0 0      0 0
+120021   456     56
CBAR     120022  999911  121111  2212111 0      0 0      0 0
+120022   456     56
CBAR     120023  999911  221211  2213111 0      0 0      0 0
+120023   456     56
CBAR     120024  999911  221112  3212121 0      0 0      0.0
+120024   456     56
CBAR     120025  999911  321212  3213121 0      0 0      0 0
+120025   456     56
CBAR     120026  999911  221113  3212131 0      0 0      0 0
+120026   456     56
CBAR     120027  999911  221211  4212121 0      0 0      0 0
+120027   456     56
CBAR     120028  999911  421212  4212131 0      0 0      0 0
+120028   456     56
CBAR     120029  999911  221311  4213121 0      0 0      0 0
+120029   456     56
CBAR     120030  999911  121112  4212121 0      0 0      0 0
+120030   456     56
CBAR     120031  999911  421212  4213121 0      0 0      0 0
+120031   456     56
CBAR     120032  999911  121113  4212131.0      0 0      0 0
+120032   456     56
$ VERTICAL BEAMS
CBAR     120033  999962  111111  1211110 0      1 0      0 0
+120033    56    456
CBAR     120034  999962  111112  1211120 0      1 0      0 0
+120034    56    456
CBAR     120035  999962  211112  2211120 0      1 0      0 0
+120035    56    456
CBAR     120036  999962  111113  1211130 0      1 0      0 0
+120036    56    456
CBAR     120037  999962  211113  2211130 0      1 0      0 0
+120037    56    456
CBAR     120038  999962  111211  1212110 0      1 0      0 0
+120038    56    456
CBAR     120039  999962  211211  2212110 0      1 0      0 0
+120039    56    456
CBAR     120040  999962  111212  1212120.0      1 0      0 0
+120040    56    456
CBAR     120041  999962  211212  2212120 0      1 0      0 0
+120041    56    456
CBAR     120042  999962  311212  3212120 0      1 0      0 0
+120042    56    456
CBAR     120043  999962  411212  4212120 0      1 0      0 0
+120043    56    456
CBAR     120044  999962  111213  1212130 0      1 0      0 0
+120044    56    456
CBAR     120045  999962  211213  2212130 0      1 0      0 0
+120045    56    456
```

```
CBAR      120046  999962  311213  3212130 0       1 0       0 0
+120046     56      456
CBAR      120047  999962  411213  4212130 0       1 0       0 0
+120047     56      456
CBAR      120048  999962  111311  1213110 0       1 0       0 0
+120048     56      456
CBAR      120049  999962  211311  2213110 0       1 0       0 0
+120049     56      456
CBAR      120050  999962  111312  1213120 0       1 0       0 0
+120050     56      456
CBAR      120051  999962  211312  2213120 0       1 0       0 0
+120051     56      456
CBAR      120052  999962  311312  3213120 0       1 0       0.0
+120052     56      456
CBAR      120053  999962  411312  4213120 0       1 0       0 0
+120053     56      456
$ HORIZONTAL DIAGONALS
CROD    140001  888811  111111  111212
CROD    140002  888811  111211  111112
CROD    150001  888811  121111  121212
CROD    150002  888811  121211  121112
CROD    140003  888811  111112  111213
CROD    140004  888811  111212  111113
CROD    150003  888811  121112  121213
CROD    150004  888811  121212  121113
CROD    140005  888811  111211  111312
CROD    140006  888811  111311  111212
CROD    150005  888811  121211  121312
CROD    150006  888811  121311  121212
CROD    140007  888811  111111  211212
CROD    140008  888811  211112  111211
CROD    140009  888811  121111  221212
CROD    140010  888811  221112  121211
CROD    140011  888811  111111  311212
CROD    140012  888811  211112  211211
CROD    140013  888811  121111  321212
CROD    140014  888811  221112  221211
CROD    140015  888811  111111  411212
CROD    140016  888811  111112  211211
CROD    140017  888811  121111  421212
CROD    140018  888811  121112  221211
CROD    140019  888811  211112  211213
CROD    140020  888811  211113  211212
CROD    140021  888811  221112  221213
CROD    140022  888811  221113  221212
CROD    140023  888811  211112  311213
CROD    140024  888811  211113  311212
CROD    140025  888811  221112  321213
CROD    140026  888811  221113  321212
CROD    140027  888811  111112  411213
CROD    140028  888811  111113  411212
```

```
CROD     140029  888811  121112  421213
CROD     140030  888811  121113  421212
CROD     140031  888811  111211  211312
CROD     140032  888811  211212  111311
CROD     140033  888811  121211  221312
CROD     140034  888811  221212  121311
CROD     140035  888811  211211  311312
CROD     140036  888811  311212  211311
CROD     140037  888811  221211  321312
CROD     140038  888811  321212  221311
CROD     140039  888811  211211  411312
CROD     140040  888811  411212  211311
CROD     140041  888811  221211  421312
CROD     140042  888811  421212  221311
$ VERTICAL DIAGONALS
CROD     160001  888811  121111  111112
CROD     160002  888811  121112  111111
CROD     160003  888811  121111  111211
CROD     160004  888811  121211  111111
CROD     160005  888811  121112  111113
CROD     160006  888811  121113  111112
CROD     160007  888811  121211  111311
CROD     160008  888811  121311  111211
CROD     160009  888811  121211  111212
CROD     160010  888811  121212  111211
CROD     160011  888811  121112  111212
CROD     160012  888811  121212  111112
CROD     160013  888811  121212  111213
CROD     160014  888811  121213  111212
CROD     160015  888811  121212  111312
CROD     160016  888811  121312  111212
CROD     160017  888811  121311  111312
CROD     160018  888811  121312  111311
CROD     160019  888811  121113  111213
CROD     160020  888811  121213  111113
CROD     260001  888811  121111  211112
CROD     260002  888811  221112  111111
CROD     260003  888811  221112  211113
CROD     260004  888811  221113  211112
CROD     260005  888811  121211  211212
CROD     260006  888811  221212  111211
CROD     260007  888811  221112  211212
CROD     260008  888811  221212  211112
CROD     260009  888811  221212  211213
CROD     260010  888811  221213  211212
CROD     260011  888811  221212  211312
CROD     260012  888811  221312  211212
CROD     260013  888811  121311  211312
CROD     260014  888811  221312  111311
CROD     260015  888811  221113  211213
CROD     260016  888811  221213  211113
CROD     360001  888811  121111  211211
CROD     360002  888811  221211  111111
```

CROD	360003	888811	221211	211311
CROD	360004	888811	221311	211211
CROD	360005	888811	221211	311212
CROD	360006	888811	321212	211211
CROD	360007	888811	221112	311212
CROD	360008	888811	321212	211112
CROD	360009	888811	321212	311213
CROD	360010	888811	321213	311212
CROD	360011	888811	321212	311312
CROD	360012	888811	321312	311212
CROD	360013	888811	221311	311312
CROD	360014	888811	321312	211311
CROD	360015	888811	221113	311213
CROD	360016	888811	321213	211113
CROD	460001	888811	221211	411212
CROD	460002	888811	421212	211211
CROD	460003	888811	121112	411212
CROD	460004	888811	421212	111112
CROD	460005	888811	421212	411213
CROD	460006	888811	421213	411212
CROD	460007	888811	421212	411312
CROD	460008	888811	421312	411212
CROD	460009	888811	221311	411312
CROD	460010	888811	421312	211311
CROD	460011	888811	121113	411213
CROD	460012	888811	421213	111113

```
$ BEAM PROPERTIES
PBEAM    999911  911        3 9E-04 1 2E-07 1 2E-07 0       2 5E-07 0       +9999111
+9999111                                                                    +9999112
+9999112NO       0 5        3 9E-04 1 2E-07 1 2E-07 0       2 5E-07 0       +9999113
+9999113NO       1 0        3 9E-04 1 2E-07 1 2E-07 0       2 5E-07 0
PBEAM    999912  911        0       0       0       0       0       0       +9999121
+9999121                                                                    +9999122
+9999122NO       0 5        0       0       0       0       0       0       +9999123
+9999123NO       1 0        0       0       0       0       0       0
MAT1     911      1 4E+11 2 1E+10 3 0E-01 1 9E+03 0         0       0
PBEAM    999961  912        5 1E-04 1 5E-09 1 5E-09 0       3 0E-09 0       +9999611
+9999611                                                                    +9999612
+9999612NO       0 5        5 1E-04 1 5E-09 1 5E-09 0       3 0E-09 0       +9999613
+9999613NO       1 0        5 1E-04 1 5E-09 1 5E-09 0       3 0E-09 0
PBEAM    999962  912        9 9E-04 5 7E-09 5 7E-09 0       1 1E-08 0       +9999621
+9999621                                                                    +9999622
+9999622NO       0 5        9 9E-04 5 7E-09 5 7E-09 0       1 1E-08 0       +9999623
+9999623NO       1 0        9 9E-04 5 7E-09 5 7E-09 0       1 1E-08 0
PBEAM    999963  912        0       0       0       0       0       0       +9999631
+9999631                                                                    +9999632
+9999632NO       0 5        0       0       0       0       0       0       +9999633
+9999633NO       1 0        0       0       0       0       0       0
MAT1     912      1 4E+11 2 1E+10 3 0E-01 1 9E+03 0         0       0

$ ROD PROPERTIES
PROD     888811  811        1 3E-04 2 7E-09 0       0
PROD     888812  811        0       0       0       0
MAT1     811      1 4E+11 2 1E+10 3 0E-01 1 9E+03 0         0       0
MAT1     812      1 4E+11 2 1E+10 3 0E-01 1 9E+03 0         0       0.
```

```
$ CONCENTRATED MASSES FROM SURFACE ARRAY
CONM2     111111  111111          005
CONM2     111112  111112          005
CONM2     211112  211112          005
CONM2     111113  111113          005
CONM2     211113  211113          005
CONM2     111211  111211          005
CONM2     211211  211211          005
CONM2     111212  111212          005
CONM2     211212  211212          005
CONM2     311212  311212          005
CONM2     411212  411212          005
CONM2     111213  111213          005
CONM2     211213  211213         .005
CONM2     311213  311213          005
CONM2     411213  411213          005
CONM2     111311  111311          005
CONM2     211311  211311          005
CONM2     111312  111312          005
CONM2     211312  211312          005
CONM2     311312  311312          005
CONM2     411312  411312          005
CONM2     121111  121111        4 681
CONM2     121112  121112        4 681
CONM2     221112  221112        4 681
CONM2     121113  121113        4 681
CONM2     221113  221113        4 681
CONM2     121211  121211        4 681
CONM2     221211  221211        4 681
CONM2     121212  121212        4 681
CONM2     221212  221212        4 681
CONM2     321212  321212        4 681
CONM2     421212  421212        4 681
CONM2     121213  121213        4 681
CONM2     221213  221213        4 681
CONM2     321213  321213        4 681
CONM2     421213  421213        4 681
CONM2     121311  121311        4.681
CONM2     221311  221311        4 681
CONM2     121312  121312        4 681
CONM2     221312  221312        4 681
CONM2     321312  321312        4 681
CONM2     421312  421312        4 681
$ GRAVITY LOADINGS
GRAV    100                   0 00 0 00000 0 00000 0 00000
GRAV    200                   0 00 0.00000 0 00000 0 00000
$ PARAMETERS
PARAM   GRDPNT  100000
ENDDATA
```

END OF DYCI

LISTING OF DYHC

```
BEGIN BULK
$  DATA FOR HOOP AND COLUMN CONFIGURATION
$  INCLUDING FORE STAYS, BACK STAYS
$  INCLUDING CENTRAL STAYS
$  HOOP DIAMETER, COLUMN HEIGHT =  100 00  100 00
$  COLUMN GRID, ELEMENTS AND PROPERTIES
GRID         101              0 00     0 00     0 00
GRID         102              0 00     0 00    10 00
CBAR         101     101      101      102      501
PBAR         101     1001 17E-011 08E+001 08E+002 15E+00
GRID         103              0 00     0 00    20 00
CBAR         102     102      102      103      501
PBAR         102     1001 50E-017.25E-017 25E-011 45E+00
GRID         104              0 00     0 00    30 00
CBAR         103     103      103      104      501
PBAR         103     1001 83E-013 75E-013 75E-017 50E-01
GRID         105              0 00     0 00    53 33
CBAR         104     104      104      105      501
PBAR         104     1001 40E-018 25E-018 25E-011 65E+00
GRID         106              0 00     0 00    76 67
CBAR         105     105      105      106      501
PBAR         105     1001 07E-011.18E+001 18E+002 35E+00
GRID         107              0 00     0 00   100 00
CBAR         106     106      106      107      501
PBAR         106     1007 38E-021 53E+001 53E+003 05E+00
$  CONCENTRATED MASS FOR COLUMN
CONM2      10107     107             300 000
CONM2      10101     101            1000 000
CONM2      10104     104             235 619
MAT1         1001 32E+111 51E+10          1 90E+03
$  HOOP GRID, ELEMENTS, PROPERTIES AND MATERIALS
GRID           5              0 00     0 00    25 00            123456
GRID         501              0 00    50 00    25 00
CBAR         501     500      501      502        5
CONM2       8501     501              22 907
GRID         502             12 94    48 30    25 00
CBAR         502     500      502      503        5
CONM2       8502     502              22 907
GRID         503             25 00    43 30    25 00
CBAR         503     500      503      504        5
CONM2       8503     503              22 907
GRID         504             35 36    35 36    25 00
CBAR         504     500      504      505        5
CONM2       8504     504              22 907
GRID         505             43 30    25 00    25 00
CBAR         505     500      505      506        5
CONM2       8505     505              22 907
GRID         506             48 30    12 94    25 00
CBAR         506     500      506      507        5
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CONM2	8506	506		22 907	
GRID	507		50 00	00	25 00
CBAR	507	500	507	508	5
CONM2	8507	507		22 907	
GRID	508		48 30	-12 94	25 00
CBAR	508	500	508	509	5
CONM2	8508	508		22 907	
GRID	509		43 30	-25 00	25 00
CBAR	509	500	509	510	5
CONM2	8509	509		22 907	
GRID	510		35 36	-35 36	25 00
CBAR	510	500	510	511	5
CONM2	8510	510		22 907	
GRID	511		25 00	-43 30	25 00
CBAR	511	500	511	512	5
CONM2	8511	511		22 907	
GRID	512		12 94	-48 30	25 00
CBAR	512	500	512	513	5
CONM2	8512	512		22 907	
GRID	513		00	-50 00	25 00
CBAR	513	500	513	514	5
CONM2	8513	513		22 907	
GRID	514		-12 94	-48 30	25 00
CBAR	514	500	514	515	5
CONM2	8514	514		22 907	
GRID	515		-25 00	-43 30	25 00
CBAR	515	500	515	516	5
CONM2	8515	515		22 907	
GRID	516		-35 36	-35 36	25 00
CBAR	516	500	516	517	5
CONM2	8516	516		22 907	
GRID	517		-43 30	-25 00	25 00
CBAR	517	500	517	518	5
CONM2	8517	517		22 907	
GRID	518		-48 30	-12 94	25 00
CBAR	518	500	518	519	5
CONM2	8518	518		22 907	
GRID	519		-50 00	- 00	25 00
CBAR	519	500	519	520	5
CONM2	8519	519		22 907	
GRID	520		-48 30	12 94	25 00
CBAR	520	500	520	521	5
CONM2	8520	520		22 907	
GRID	521		-43 30	25 00	25 00
CBAR	521	500	521	522	5
CONM2	8521	521		22 907	
GRID	522		-35 36	35 36	25 00
CBAR	522	500	522	523	5
CONM2	8522	522		22 907	

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GRID           523           -25 00    43 30    25 00
CBAR           523      500      523      524        5
CONM2         8523      523              22 907
GRID           524           -12 94    48 30    25 00
CBAR           524      500      524      501        5
CONM2         8524      524              22 907
PBAR           500      5004 50E-039 60E-061 07E-051 21E-05
MAT1           5007 01E+101 01E+10         2 00E+03
$  STAY ATTACH SYSTEM GRID, ELEMENTS
$  DATA FOR HOOP POINT  1
GRID           201             0 00       50     0 00
PLOTEL        1201      101      201
RBE2          2201      101123456         201
GRID           301             0 00       25    30 00
PLOTEL        1301      104      301
RBE2          2301      104123456         301
GRID           401             0 00       50   100 00
PLOTEL        1401      107      401
RBE2          2401      107123456         401
CROD         12001      200      201      501
CROD         14001      400      401      501
$  DATA FOR HOOP POINT  2
GRID           202               13       48     0 00
PLOTEL        1202      101      202
RBE2          2202      101123456         202
GRID           302               06       24    30 00
PLOTEL        1302      104      302
RBE2          2302      104123456         302
GRID           402               13       48   100 00
PLOTEL        1402      107      402
RBE2          2402      107123456         402
CROD         12002      200      202      502
CROD         14002      400      402      502
$  DATA FOR HOOP POINT  3
GRID           203               25       43     0 00
PLOTEL        1203      101      203
RBE2          2203      101123456         203
GRID           303               13       22    30 00
PLOTEL        1303      104      303
RBE2          2303      104123456         303
GRID           403               25       43   100 00
PLOTEL        1403      107      403
RBE2          2403      107123456         403
CROD         12003      200      203      503
CROD         14003      400      403      503
$  DATA FOR HOOP POINT  4
GRID           204               35       35     0 00
PLOTEL        1204      101      204
RBE2          2204      101123456         204
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GRID           304                   18         18    30 00
PLOTEL        1304       104        304
RBE2          2304       104123456              304
GRID           404                   35         35   100 00
PLOTEL        1404       107        404
RBE2          2404       107123456              404
CROD         12004       200        204         504
CROD         14004       400        404         504
$  DATA FOR HOOP POINT   5
GRID           205                   43         25     0 00
PLOTEL        1205       101        205
RBE2          2205       101123456              205
GRID           305                   22         13    30 00
PLOTEL        1305       104        305
RBE2          2305       104123456              305
GRID           405                   43         25   100 00
PLOTEL        1405       107        405
RBE2          2405       107123456              405
CROD         12005       200        205         505
CROD         14005       400        405         505
$  DATA FOR HOOP POINT   6
GRID           206                   48         13     0 00
PLOTEL        1206       101        206
RBE2          2206       101123456              206
GRID           306                   24         06    30 00
PLOTEL        1306       104        306
RBE2          2306       104123456              306
GRID           406                   48         13   100 00
PLOTEL        1406       107        406
RBE2          2406       107123456              406
CROD         12006       200        206         506
CROD         14006       400        406         506
$  DATA FOR HOOP POINT   7
GRID           207                   50         00     0 00
PLOTEL        1207       101        207
RBE2          2207       101123456              207
GRID           307                   25         00    30 00
PLOTEL        1307       104        307
RBE2          2307       104123456              307
GRID           407                   50         00   100 00
PLOTEL        1407       107        407
RBE2          2407       107123456              407
CROD         12007       200        207         507
CROD         14007       400        407         507
$  DATA FOR HOOP POINT   8
GRID           208                   48       - 13     0 00
PLOTEL        1208       101        208
RBE2          2208       101123456              208
GRID           308                   24       - 06    30 00
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PLOTEL      1308     104      308
RBE2        2308     104123456         308
GRID         408               48    - 13   100 00
PLOTEL      1408     107      408
RBE2        2408     107123456         408
CROD       12008     200      208      508
CROD       14008     400      408      508
$  DATA FOR HOOP POINT  9
GRID         209               43    - 25     0 00
PLOTEL      1209     101      209
RBE2        2209     101123456         209
GRID         309               22    - 13    30 00
PLOTEL      1309     104      309
RBE2        2309     104123456         309
GRID         409               43    - 25   100 00
PLOTEL      1409     107      409
RBE2        2409     107123456         409
CROD       12009     200      209      509
CROD       14009     400      409      509
$  DATA FOR HOOP POINT 10
GRID         210               35    - 35     0 00
PLOTEL      1210     101      210
RBE2        2210     101123456         210
GRID         310               18    - 18    30 00
PLOTEL      1310     104      310
RBE2        2310     104123456         310
GRID         410               35    - 35   100 00
PLOTEL      1410     107      410
RBE2        2410     107123456         410
CROD       12010     200      210      510
CROD       14010     400      410      510
$  DATA FOR HOOP POINT 11
GRID         211               25    - 43     0 00
PLOTEL      1211     101      211
RBE2        2211     101123456         211
GRID         311               13    - 22    30 00
PLOTEL      1311     104      311
RBE2        2311     104123456         311
GRID         411               25    - 43   100 00
PLOTEL      1411     107      411
RBE2        2411     107123456         411
CROD       12011     200      211      511
CROD       14011     400      411      511
$  DATA FOR HOOP POINT 12
GRID         212               13    - 48     0 00
PLOTEL      1212     101      212
RBE2        2212     101123456         212
GRID         312               06    - 24    30 00
PLOTEL      1312     104      312
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RBE2           2312      104123456        312
GRID            412             13      - 48   100 00
PLOTEL         1412      107      412
RBE2           2412      107123456        412
CROD          12012      200      212     512
CROD          14012      400      412     512
$  DATA FOR HOOP POINT 13
GRID            213             00      - 50     0 00
PLOTEL         1213      101      213
RBE2           2213      101123456        213
GRID            313             00      - 25    30 00
PLOTEL         *313      104      313
RBE2           2313      104123456        313
GRID            413             00      - 50Ph100 00
PLOTEL         1413      107      413
RBE2           2413      107123456        413
CROD          12013      200      213     513
CROD          14013      400      413     513
$  DATA FOR HOOP POINT 14
GRID            214           - 13      - 48     0 00
PLOTEL         1214      101      214
RBE2           2214      101123456        214
GRID            314           - 06      - 24    30 00
PLOTEL         1314      104      314
RBE2           2314      104123456        314
GRID            414           - 13      - 48   100 00
PLOTEL         1414      107      414
RBE2           2414      107123456        414
CROD          12014      200      214     514
CROD          14014      400      414     514
$  DATA FOR HOOP POINT 15
GRID            215           - 25      - 43     0 00
PLOTEL         1215      101      215
RBE2           2215      101123456        215
GRID            315           - 13      - 22    30 00
PLOTEL         1315      104      315
RBE2           2315      104123456        315
GRID            415           - 25      - 43   100 00
PLOTEL         1415      107      415
RBE2           2415      107123456        415
CROD          12015      200      215     515
CROD          14015      400      415     515
$  DATA FOR HOOP POINT 16
GRID            216           - 35      - 35     0 00
PLOTEL         1216      101      216
RBE2           2216      101123456        216
GRID            316           - 18      - 18    30 00
PLOTEL         1316      104      316
RBE2           2316      104123456        316
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GRID          416              - 35    - 35  100 00
PLOTEL       1416      107      416
RBE2         2416      107123456        416
CROD        12016      200      216     516
CROD        14016      400      416     516
$  DATA FOR HOOP POINT 17
GRID          217              - 43    - 25    0 00
PLOTEL       1217      101      217
RBE2         2217      101123456        217
GRID          317              - 22    - 13   30 00
PLOTEL       1317      104      317
RBE2         2317      104123456        317
GRID          417              - 43    - 25  100 00
PLOTEL       1417      107      417
RBE2         2417      107123456        417
CROD        12017      200      217     517
CROD        14017      400      417     517
$  DATA FOR HOOP POINT 18
GRID          218              - 48    - 13    0 00
PLOTEL       1218      101      218
RBE2         2218      101123456        218
GRID          318              - 24    - 06   30 00
PLOTEL       1318      104      318
RBE2         2318      104123456        318
GRID          418              - 48    - 13  100 00
PLOTEL       1418      107      418
RBE2         2418      107123456        418
CROD        12018      200      218     518
CROD        14018      400      418     518
$  DATA FOR HOOP POINT 19
GRID          219              - 50    - 00    0 00
PLOTEL       1219      101      219
RBE2         2219      101123456        219
GRID          319              - 25    - 00   30.00
PLOTEL       1319      104      319
RBE2         2319      104123456        319
GRID          419              - 50    - 00  100 00
PLOTEL       1419      107      419
RBE2         2419      107123456        419
CROD        12019      200      219     519
CROD        14019      400      419     519
$  DATA FOR HOOP POINT 20
GRID          220              - 48      13    0 00
PLOTEL       1220      101      220
RBE2         2220      101123456        220
GRID          320              - 24      06   30 00
PLOTEL       1320      104      320
RBE2         2320      104123456        320
GRID          420              - 48      13  100 00
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PLOTEL        1420       107       420
RBE2          2420       107123456         420
CROD         12020       200       220     520
CROD         14020       400       420     520
$  DATA FOR HOOP POINT 21
GRID           221               - 43       25      0 00
PLOTEL        1221       101       221
RBE2          2221       101123456         221
GRID           321               - 22       13     30 00
PLOTEL        1321       104       321
RBE2          2321       104123456         321
GRID           421               - 43       25    100 00
PLOTEL        1421       107       421
RBE2          2421       107123456         421
CROD         12021       200       221     521
CROD         14021       400       421     521
$  DATA FOR HOOP POINT 22
GRID           222               - 35       35      0 00
PLOTEL        1222       101       222
RBE2          2222       101123456         222
GRID           322               - 18       18     30 00
PLOTEL        1322       104       322
RBE2          2322       104123456         322
GRID           422               - 35       35    100 00
PLOTEL        1422       107       422
RBE2          2422       107123456         422
CROD         12022       200       222     522
CROD         14022       400       422     522
$  DATA FOR HOOP POINT 23
GRID           223               - 25       43      0 00
PLOTEL        1223       101       223
RBE2          2223       101123456         223
GRID           323               - 13       22     30 00
PLOTEL        1323       104       323
RBE2          2323       104123456         323
GRID           423               - 25       43    100 00
PLOTEL        1423       107       423
RBE2          2423       107123456         423
CROD         12023       200       223     523
CROD         14023       400       423     523
$  DATA FOR HOOP POINT 24
GRID           224               - 13       48      0 00
PLOTEL        1224       101       224
RBE2          2224       101123456         224
GRID           324               - 06       24     30 00
PLOTEL        1324       104       324
RBE2          2324       104123456         324
GRID           424               - 13       48    100 00
PLOTEL        1424       107       424
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RBE2          2424      107123456       424
CROD         12024      200        224      524
CROD         14024      400        424      524
PROD           200      2001  50E-060
PROD           300      3001  10E-060
PROD           400      4001  10E-060
MAT1           2001  27E+111  53E+10          1  91E+03
MAT1           3001  38E+112.30E+10           1  94E+03
MAT1           4001  30E+111  50E+10          1  91E+03
$   MISCELLANEOUS  DATA
PARAM     GRDPNT          101
SPC1           100123456         101
GRAV            1              9  81         01      0  00      0  00
GRAV            2              9  81     0  00         01      0  00
GRAV            3              9  81     0  00     0  00         01
ENDDATA
 -  EOR--
```

END OF DYHC LISTING

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